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HYDROGRAPH SYNTHESIS USING LANDSAT REMOTE SENSING AND THE SCS MODELS

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JULY 1976

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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Robert M. Ragan[1]

Thomas J. Jackson[2]

ABSTRACT

The land cover requirements of the Soil Conservation Service (SCS) Model used for hydrograph synthesis in urban areas were modified to be Landsat compatible. The Curve Numbers obtained with these alternate land cover categories compare well with those obtained in published example problems using the conventional categories. Emergency spillway hydrographs and synthetic flood frequency flows computed for a 21.1 sq. mi. test area showed excellent agreement between the conventional aerial photo-based and the Landsat-based SCS approaches.

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CONTENTS

ILLUSTRATIONS

TABLES

HYDROGRAPH SYNTHESIS USING
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I. INTRODUCTION

Traditionally the planning and design of Urban Drainage Systems focused on the simple objective of moving runoff from an area as quickly and with as little cost as possible. Today, socio-economic and environmental considerations require that planning and design be conducted within the framework of an overall stormwater management system. Consideration must be given to the protection of downstream land uses through such innovations as on-site detention storage, adjusting the timing of runoff through channel modification, and provisions for minimizing changes in water quality. These more sophisticated design and planning requirements have led to the development of a number of computer-based mathematical models intended to simulate both the quantity and quality of runoff from urban areas. These models vary in their structure and some are considered primarily as planning tools while others are much more detailed and intended for design purposes. Regardless of the particular structure of the models, most require land cover information to define the hydrologic parameters needed as inputs.

The advantage of a model having parameters defined in terms of land cover is that it allows experimentation with alternate forms of development and the assessment of future changes that might occur. The basic approach is to calibrate a model to reflect the hydrologic regime produced by the existing land

cover and drainage system. Once the planner is satisfied that the model adequately represents his existing system, he is then able to evaluate the impact of land cover changes and alternate water management projects. Used in this manner, the hydrologic model becomes an important tool in water resources planning.

Unfortunately, collection of the necessary land cover information and its translation into hydrologic parameters is rather difficult, especially when a large watershed is involved. It is not uncommon for a model to have a reduced utility because it was not possible to define the land use distributions within the available time and funding constraints. Trade-offs between accuracy of the model parameters and the time or money available for their determination must be made. Because of the necessity of such trade-offs, a study was conducted to investigate the use of computer aided analysis of Landsat multispectral data for estimating the land cover distributions needed for the operation of a model that is representative of those in current practice. The model selected was that developed by the Soil Conservation Service (SCS) of the United States Department of Agriculture[1,2,3]. The land covers emphasized were those needed for models being used in suburban areas adjacent to metropolitan centers.

The following sections attempt to meet several objectives. Section II provides the reader with an overview of the SCS Model requirements. Section III discusses the limitations of Landsat relative to the conventional model requirements and presents an alternate land cover that can be defined through computer aided analysis of the Landsat Multispectral scanner (MSS) computer compatible

tapes (CCT). The impact of using Landsat-compatible land cover as an alternative to the more detailed conventional requirements of the SCS Model are examined in Section IV through comparisons with the example problems presented in SCS-TR-55[1].

A step by step example problem illustrating the use of the Landsat compatible land cover is presented in Section V. Section V centers on the computation of an emergency spillway hydrograph for an SCS Class b structure that would be placed at the lower end of the 21.1 square mile Northwest Branch Watershed in the Maryland suburbs of Washington, D. C. The Landsat-based hydrograph is then compared with that computed with the more detailed traditional input data obtained from color infrared aerial photography and digitized soil maps.

Section VI compares the synthetic flood frequency series for the Northwest Branch obtained by three different approaches with the SCS Models. The relatively simple hand computation version of the SCS Model described in Chapter 21 of SCS-NEH-4[2] was used to generate peak discharges using, first, Landsat compatible, and then, traditional air-photo based inputs. These peak discharges were then compared with those produced by the SCS-TR-20[3]. The "TR-20" is an extensive computer package that broke the watershed into 109 sub-areas and routed the flows through 120 channel cross-sections that had been surveyed and entered as input to the model.

II. OVERVIEW OF THE SCS MODEL

There are a number of versions of the SCS model described in (1, 2, and 3). All versions require land cover and soil descriptions, but the sub-models used to compute the discharges range from quite simple to very complex. The approach emphasized in the present study is that recommended for use in the computation of emergency spillway hydrographs in Chapter 21 of SCS-NEH-4[2]. The textbook by Viessman, Harbaugh, and Knapp[4] has an excellent description of this version of the SCS Models. For a more comprehensive discussion of the SCS approach than that presented in this section, the reader is referred to the above citations.

The SCS Models compute direct runoff through the use of a set of curves, or their formulations in computer based versions, that were developed from field studies that measured runoff for numerous soil-land cover complexes. These curves define a Curve Number, CN, that is a function of land cover and soil type. Table I, reproduced from (1), illustrates the approach used in selecting the Curve Number.

The four hydrologic soil types are classified in accordance with the following criteria:

A. (Low runoff potential) Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. They have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well

drained soils with moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture.

D. (High runoff potential) Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

County Soil Surveys define the distribution of the soils by name. Once the name of the soil is known, the hydrologic classification can be obtained from tables in the SCS-NEH-4[2], or those reproduced in Chow[5]. Table II illustrates one page of these tabulations.

Once the Curve Number has been selected, Figure 1 (Fig. 10.1 of Ref. 2) is used to compute the direct runoff from the rainfall. As will be subsequently illustrated by examples in Section V, a series of equations, figures, and tables are then used to compute the hydrograph.

There were several reasons for selecting the SCS Model for detailed study. First, it is a hydrologic as opposed to a hydraulic model. In a hydrologic model, the runoff is estimated through quite simple equations that "lump" the watershed processes through coefficients based on average land use or other basin

characteristics. A hydraulic model, on the other hand, requires detailed definition of such factors as length of overland flow, channel cross-sections, roughness coefficients, and structure of the linkages of the flow systems. These details are necessary because the hydraulic model estimates runoff by simulating the individual watershed processes through a series of physically-based mathematical sub-models. A previous study[6] indicated that land covers could be defined from Landsat with the resolution required for the hydrologic, but not the hydraulic models.

A second reason for selecting the SCS Model rests in its wide use. Many of the watershed development projects in urban areas use funds available through PL-566, the Watershed Protection and Flood Protection Act of 1954. When PL-566 funds are involved, the SCS monitors the design of the flood control facilities and requires the use of some form of the SCS Model to determine flows and stages.

Finally, the SCS Model is typical of the coefficient based hydrologic models. For example, it is similar to the recently developed STORM[7] which will be used by the U. S. Army Corps of Engineers in its Urban Studies Program[8] in that a runoff coefficient is defined based on land use. The two models are dissimilar in that STORM is a continuous streamflow generator while the SCS model is a single event model. Still, any successes experienced in modifying the SCS package to use Landsat data can be applied to STORM or other models.

III. MODIFICATION FOR LANDSAT COMPATIBILITY

The Landsat multispectral scanner (MSS) does not have the resolution required to consistently classify the land uses listed in Table I. Therefore, it is necessary to develop an alternate series of land use categories that can be identified with Landsat and still yield Curve Numbers that are in reasonable agreement with those of Table I. First, it must be recognized that the Curve Numbers presented by SCS are not precise coefficients. Rather, they represent "best fits" to the small watershed rainfall-runoff data upon which the model is based. Figure 2, (Figure 10.2 of Ref. 2) is a plot of the field data used to develop the Curve Numbers. The term, I_a, is the initial abstraction from the rainfall and S is the sum of I_a and the maximum potential abstraction. The Curve Number is related to S by the relationship

$$CN = \frac{1000}{S + 10} \tag{1}$$

Figure 2 clearly shows that a significant standard error is associated with Equation 1. Thus, any proposed alternate land use classification can show some deviation from the Curve Numbers of Table I without seriously detracting from the overall SCS Model.

Table III is an alternate approach to defining Curve Numbers and includes only classifications that computer aided analysis of the Landsat MSS CCT's can identify. The discussions in (6) conclude that these categories can be identified with a large degree of agreement with the results obtained from low altitude aerial photography. The Curve Numbers for Table III were obtained as follows:

(1) All Forest Land was assumed to be in good cover. The Curve Numbers of Table III are those of Table I.

(2) Grassed Open Space - To develop the Curve Numbers for this category, the average of the Table I categories of "Good Pasture," "Good Meadow," and "Good Condition Lawns, Parks, Golf Courses, etc." were used.

Example: Soil Group A

(Pasture(39) + Meadow(30) + Grass Lawn(39))/3 = 36

(3) Highly Impervious (Commercial-Industrial-Large Parking Lot) - The Table III Curve Number is the average of the following Table I categories: "Commercial and Business (I = 85%)"; "Industrial (I = 72%)"; and "Pavements."

Example: Soil Group A

$$CN = (89 + 81 + 98)/3 = 90$$

(4) Residential - At present Landsat is not able to discriminate different residential lot sizes, densities, etc. Thus, the Table III category includes a spectrum of lot sizes and some "low density" or "garden type" multifamily housing. The Curve Numbers presented in Table III are the average of the "Residential" Curve Numbers for each soil group in Table I.

Example: Soil Group A

$$CN = (77 + 61 + 57 + 54 + 51)/5 = 60$$

(5) Bare Ground - The Table III Curve Numbers are the average of the "Dirt Road" and "Cultivated Land Without Conservation Treatment" categories of Table I.

Example: Soil Group D

$$CN = (89 + 91)/2 = 90$$

(6) Cultivated - During fallow periods, the land under cultivation would normally be classified as "Bare Ground." If the cultivated area is "without conservation practice," the Curve Numbers will be essentially those of "Bare Ground." Some of the Land Use-Curve Number tables in SCS-NEH-4[2] assign values to various types of crops. Numerous studies by Purdue University's Laboratory for Applications of Remote Sensing and others have shown that discrimination among crop types can be accomplished with good accuracy with Landsat. Thus, contingent on ground truth in the area of application, it should be possible to modify Table III to include crop types if needed.

It must be emphasized that Landsat is proposed only for use in the identification of the land covers needed for an alternate approach to the SCS Model. The hydrologist must still have a topographic map to delineate the watershed boundaries and define the slope and length of the channel system. He must also have some definition of the soils on the watershed. Thus, in this context, the use of Landsat is presented as a more efficient technique to provide part of the information needed to apply the SCS Model.

The land cover categories presented in Table III were selected as being appropriate for use in the suburban areas surrounding metropolitan centers in the eastern United States. For use in other geographical areas, different Landsat compatible categories can be substituted. In arid regions, for example, other cover conditions might replace forests and grasslands. The categories used are dependent on need and availability of ground truth. Still, it must be recognized that the number of land cover categories in a given table must be limited if Landsat discrimination is to be accomplished.

The two sets of comparisons follow that illustrate the agreement between the results obtained with Table I and those given with Table III. Section IV compares the Landsat compatible approach to a set of examples from Reference (1). Section V is a comparison of the approaches using a Landsat land cover delineation and Table III with a land cover identification based on high altitude photography and Table I in the Upper Anacostia River Basin in the Maryland suburbs of Washington, D. C. This test on the Upper Anacostia compares not only the sensors and Table I and III, but also the differences caused by using detailed soil and watershed slope information against "rough" soil and slope data.

IV. COMPARISON OF LANDSAT COMPATIBLE AND CONVENTIONAL LAND COVER INPUTS USING EXAMPLES FROM SCS-TR-55

The following problems are the examples presented in SCS-TR-55 to illustrate the use of their Urban Hydrologic Model. In each instance, the original approach to the problem solution is presented. The example problem is then

re-worked using Table III, the Landsat compatible land cover, to define the Curve Number.

<u>Example 2-1</u>. Compute the runoff from five inches of rainfall for a 1000 acre watershed to be converted to a suburban development. All soils are in hydrologic soil group C. The proposed land use is 50% detached houses with lot size 1/4 acre; 10% townhouses with lot size 1/8 acre; 25% streets with curbs and gutters, schools, parking lots, plazas; 15% open space parks, schoolyards, etc. with good grass cover.

A. Table I approach:

1. Compute the weighted runoff Curve Number.

Land Use	Percent	Curve Number	Product
Detached houses with lot size 1/4 acre	50	83	4,150
Townhouses with lot size 1/8 acre	10	90	900
Streets with curbs, plazas, etc.	25	98	2,450
Open space, parks, etc.	15	74	1,110
	100		8,610

Thus

$$\text{Weighted CN} = \frac{8,610}{100} = 86$$

2. From Figure 1 using CN = 86 and P = 5 read Q = 3.47 inches.

B. Table III approach:

1. The detached and town houses would have been classified as "Residential" by Landsat: CN = 83

2. The Plazas, Parking Lots, etc. would have been classified as "Highly Impervious": CN = 93

3. The Parks, etc., would have been classified as "Grassed Open Space": CN = 73

4. CN = .6(83) + .25(93) + .15(73) = 84.1   Use 84

5. From Figure 1, Q = 3.27 inches

Example 2-2. Compute the runoff from 6.3 inches of rainfall for a 1000 acre watershed to be converted to suburban development. The soils are in hydrologic soil group B. Forty percent of the development will be impervious with all impervious areas directly connected and 60% is pervious and considered to be in good grass.

A. Table I approach:

1. From Table I Pervious CN = 61

2. From Figure 3 read CN = 76; from Figure 1 Q = 3.64 inches

B. Table III approach:

1. 40% I, Consider as 40% Highly Impervious CN = 93

2. 60% Grass, CN = 60

3. .4(93) + .6(60) = 37 + 36 = 73

4. Q = 3.51 from Figure 1

Example 2-3. Compute the runoff Curve Number for a 1000 acre watershed. The hydrologic soil group is 50% B and 50% C interspersed throughout the watershed. The land use is:

1. 40% residential area that is 30% impervious

2. 12% residential area that is 65% impervious

3. 8% paved roads with open ditches

4. 10% paved roads with curbs and storm sewers

5. 16% open land with 50% fair cover and 50% good cover

6. 14% parking lots, plazas, schools, etc. (all impervious)

A. Table I approach:

	Hydrologic Soil Group					
	B			C		
Land Use	Pct.	CN	Product	Pct.	CN	Product
Residential (30 pct. Impervious)	20	72	1,440	20	81	1,620
Residential (65 pct. Impervious)	6	85	510	6	90	540
Roads with open ditches	4	89	356	4	92	368
Roads with curbs and sewers	5	98	490	5	98	490
Open land:						
Fair cover	4	69	276	4	79	316
Good cover	4	61	244	4	74	296
Parking lots, plazas, etc.	7	98	686	7	98	686
	50		4,002	50		4,316

$$\text{Weighted CN} = \frac{4,002 + 4,316}{100} = 83.18 \text{ (use 83)}$$

B. Table III approach:

1. Categories 1 through 4 cover 70% of the watershed and would have been classified as Residential by Landsat: CN = (74 + 83)/2 = 79

2. Category 5 would be classified as Grassed Open Space: CN = (60 + 73)/2 = 67

3. Category 6 would be Highly Impervious: CN = 93

4. Weighted Curve Number: CN = .7(79) + .16(67) + .14(93) = 79

Example 2-4. A 175 acre watershed consists of 30% agricultural and 70% urban land use. The agricultural land use is made up of 40% cultivated land with conservation treatment; 35% meadow in good condition and 25% in forest land with good cover. The urban area is residential with an estimated 60% on 1/3 acre lots, 25% on 1/4 acre lots, and 15% streets, and roads with storm sewers. Compute the weighted composite runoff Curve Number for a B hydrologic soil group.

A. Table I approach:

Land Use	Acres	Curve Number	Product
Agricultural	(52)		
cultivated land - cons. treat	21	71	1491
meadow - good cover	18	58	1044
forest - good cover	13	55	715
Urban	(123)		
1/3 acre lots	74	72	5328
1/4 acre lots	31	75	2325
streets and roads with curbs and storm sewers	18	98	1764
	175		12667

$$\text{Weighted CN} = \frac{12667}{175} = 72.4 \quad \text{Use CN} = 72$$

B. Table III approach:

1. Agricultural Watershed (30%)

a. Assuming that the cultivated land was open, it would have been classified as Bare Ground. No consideration would have been

given to the conservation practices because they could not be seen with Landsat: CN = 82

b. The meadow would have been classed as Grassed Open Space: CN = 60

c. Forest Land: CN = 55

d. Curve Number for Agricultural Portion of Watershed: CN = .4(82) + .35(60) + .25(55) = 68

2. Urban Watershed (70%) - The individual streets would not have been detected. The entire urban portion of the watershed would have been classified as Residential: CN = 74

3. Composite Curve Number: CN = .3(68) + .7(74) = 72.2 Use 72

V. COMPARISON OF LANDSAT AND AERIAL PHOTOGRAPHIC APPROACHES ON THE UPPER ANACOSTIA RIVER BASIN

The previous examples were hypothetical and were those included in Reference (1). Implicit in the comparison was the assumption that the Landsat would be completely accurate in identifying the appropriate land covers listed in the examples. Such will not be the case. It was also assumed in the previous examples that all of the detailed soil information would be available. Such information can be developed from the County Soil Surveys that are usually available through the State Offices of SCS. However, the development of detailed soil information is tedious and would detract from the advantage of speed offered by the Landsat approach. The following example accomplishes several things.

First, it is a "real world" problem which includes the confusion between land cover classes to which all remote sensors are subject. It also examines the impact of using a rapid estimate of soils and slopes as opposed to very detailed estimates of these parameters. Finally, the steps illustrate the approach used in the emergency spillway version of the SCS Model. The equations used in the model are presented as Table IV (Table 21.11 of Ref. 2).

PROBLEM: Compute an emergency spillway hydrograph for a Class b structure to be constructed at Colesville on the Northwest Branch of the Anacostia River.

APPROACH: Use Soil Conservation Method outlined in Chapter 21-Design Hydrographs, Section 4, SCS National Engineering Handbook[2].

A. Landsat Based Approach Using Image 100

1. Use USGS 1:24000 topographic maps to outline watershed boundary. The drainage area is found to be 21.1 square miles. Figure 4 shows tributaries and watershed boundary.

2. Develop transparency of the watershed boundary at scale of approximately 1:100,000.

3. Use Image 100 screen projector to overlay transparency of Step 2 onto the color Cathode Ray Tube display of the Landsat scene of the area surrounding the watershed under study. Black out the area not inside watershed boundary. (An alternate approach could have been

to digitize the watershed boundary and enter into the Image 100 with cards.)

4. Classify the land covers in the watershed in accordance with Table III. Obtain alpha-numeric output to insure that unclassified pixels are randomly distributed. Use listing of pixel classifications to assign percentages of watershed devoted to each land use.

   a. Figure 5 is a photoreduction of the alpha-numeric map of the Upper Anacostia produced by the Image 100

   b. Below is a listing of the pixel assignments for the Upper Anacostia

Total Pixels 10,680

Forest	2528	(23.7%)
Grassed Open Space	4068	(38.1%)
Highly Impervious	198	(1.9%)
Residential	3424	(32.1%)
Unclassified	462	(4.2%)

5. Use "General Soil Map" from the appropriate County Soil Survey published by the SCS of USDA to determine the soil associations in the Watershed. Figure 6 is the General Soil Map from the Montgomery County Soil Survey. It was not necessary to determine the exact location of the watershed on this map because of the uniformity of the soil associations in the vicinity. The Upper Anacostia centers around Norbeck and is in a Glenelg-Manor-Chester soil association. In other areas it might be necessary to outline the watershed to estimate the percentages of different associations in the watershed.

6. Use Table 7.1 of NEH-4 to determine the Hydrologic Soil Classification of the Soil Association found in Step 5. Figure 7 is an example of one page of Table 7.1. All three soils in the watershed are in the "B" Hydrologic Classification.

7. The Curve Number for the watershed can now be assigned from Table III. In the case of the Upper Anacostia:

23.7%	Forested	CN = 55
38.1%	Grassed	CN = 60
1.9%	Highly Impervious	CN = 93
23.1%	Residential	CN = 74

Weighted CN = .237(55) + .381(60) + .019(93) + .321(74) = 61.4

This accounts for only 95.8% of watershed because of 4.2% unclassified pixels: CN = 61.4/.958 = 64

8. From 1:24,000 USGS topographic sheet find the longest length channel. Estimate an average slope by measuring the distance along the channel system between contours at several points. In the Upper Anacostia, the maximum length of channel flow was found to be 46,000 ft. The average S = 0.007'/'.

9. Estimate the time of concentration by computing the time of flow down the longest channel. Some reconnaissance was necessary to develop an estimate of "n" and the flow characteristics. From limited reconnaissance, USGS Water Supply Paper 1849[9] was used to estimate n = .04. The channel bankfull hydraulic radius was approximately one foot. The Manning equation gave V = 3 ft/sec. Thus, the flow time in the channel for the Upper Anacostia was 4.26 hours.

10. In a large watershed, Step 9 is a satisfactory estimate of the time of concentration. Smaller watersheds require the additional overland flow time required for the runoff to reach the channel. This time is controlled by the length, surface material, and the land slope. To determine the overland flow time:

a. Maximum length of overland flow probably does not exceed 400 feet.

b. To find the slope, an estimate of the distribution of the subgroups within the watershed soil association must be made. The County Soil Surveys include a table entitled "Approximate Acreage and Proportionate Extent of the Soils." Figure 8 is the appropriate table from the Montgomery County Survey. Without field investigations, one can only assume that the county-wide distributions hold within the watershed. The percentages assigned to each soil are used to obtain a weighted slope. This is accomplished by multiplying the average slope of the soil by the extent. The sum of these products is then divided by the sum of the extents to obtain an average slope as shown by Table V. In the case of the Upper Anacostia, the average slope was 10.4%.

c. The velocity of overland flow is estimated from Figure 15-2 of NEH-4, presented here as Figure 9. For a forest-grass cover

on a slope of 10%, the velocity is 0.8'/sec and yields an overland flow time of 0.14 hours.

d. The total time of concentration is then the channel flow time plus the overland flow time. In the Upper Anacostia $t_c = 4.26 + .14 = 4.4$ hours.

NOTE: Steps 11 - 24 correspond to Steps 1 - 14 on Pages 21.51 - 21.53 in the example from SCS-NEH-4[2].

11. The time of concentration is less than six hours, therefore <u>Determine the 6-hour storm rainfall amount, P.</u> For this structure class the rainfall amount is taken from Figure 10a (ES-1020 of Ref. 2). For the given location the map shows that P = 8.2 inches.

12. <u>Determine the areal rainfall amount.</u> From Figure 10b (Figure 21.2a of Ref. 2) factor = .94. Therefore P = .94 (8.2) = 7.7 inches.

13. <u>Make the duration adjustment of rainfall amount.</u> No adjustment is made because the time of concentration is not over six hours.

14. <u>Determine the runoff amount, Q.</u> Enter Figure 1 (Fig. 10.1 of Ref. 2) with P = 7.7 inches and CN = 64 and find Q = 3.6 inches.

15. <u>Determine the hydrograph family.</u> Enter Figure 10c (Fig. 21.3 of Ref. 2) with CN = 64 and at P = 7.7 read hydrograph family 3.

16. <u>Determine the duration of excess rainfall, T_o.</u> Enter Figure 10d (Fig. 21.4 of Ref. 2) with P = 7.7 inches and at CN = 64 read by interpolation that $T_o = 4.4$ hours.

17. Compute the initial value of T_p. By Equation 21.4 (Table IV) this 0.7 (4.4) = 3.1 hours.

18. Compute the T_o/T_p ratio. This is 4.4/3.1 = 1.4

19. Select a revised T_o/T_p ratio from Figure 10e (Table 21.16 of Ref. 2). This table shows the hydrograph families and ratios for which dimensionless hydrographs are given in Table 21.17 of Ref. 2. Enter Figure 10e with the ratio from Step 8 and select the tabulated ratio nearest it. For this example the selected ratio, (T_o/T_p) rev., is 1.5.

20. Compute Rev. T_p. This is a revised T_p used because of the change in ratio. By Equation 21.5 (Table IV), Rev. T_p = 4.4/1.5 = 2.93 hours.

21. Compute q_p. By Equation 21.6 (Table IV) this is 484 (21.1)/2.93 = 3485 cfs.

22. Compute Q_{qp}. Using the Q from step 14 and the q_p from Step 21 gives $Q(q_p)$ = 3.6 (3485) = 12546 cfs.

23. Compute the times for which hydrograph rates will be computed. In Equation 21.7 (Table IV) use Rev. T_p from Step 10 and the entries in the t/Tp column of the selected hydrograph in Table 21.17 of Ref. 2 (presented here as Table VI). The computed times are shown in Column 2 of Table VII.

24. Compute the hydrograph rates. Use Equation 21.8 (Table IV) and the q_c/q_p column of the selected hydrograph in Table 21.17 of Ref. 2 (Table VI in this report). The computed rates are shown in Column 3 of Table VII. The hydrograph is plotted as Figure 11.

B. Aerial Photographic Approach

1. As with the Landsat approach, use 1:24000 USGS topographic map to outline watershed.

2. As the first step in developing the Curve Number, land uses in the watershed were determined from a 1:24,600 enlargement of a U-2 color infrared high altitude aerial photograph. The approach was to identify the dominant land cover in each cell of a 1/4 inch grid overlayed on the photograph. At this scale, each cell was 6.03 acres. Two interpreters were used and their results averaged to give the percentages shown in Table VIII.

3. Table I requires housing densities to obtain the Curve Number. A one inch square transparancy was overlayed onto a series of residential areas that were representative of the housing developments in the watershed. The number of houses inside the square were counted to obtain the number of dwelling units per acre as required by Table I. The density distribution is shown in Table IX.

4. The Anacostia Resource Identification Study[9,10] had developed a series of detailed soil maps using computer techniques. Figure 12

shows the distribution of Hydrologic Soil Groups. Each symbol represents the dominant soil group in a 1.15 acre cell. By counting the number of symbols assigned to each group in the watershed, the following distribution was obtained:

A	0%
B	79.9%
C	5.5%
D	14.6%

5. Curve Number was then computed as follows:

a. Calculation of Weighted CN for Residential Areas:

CN by Soil Group

	B	C	D	
1/4 Ac.	75	83	87	.799(75) + .055(83) + .146(87) = 77.2
1/3 Ac.	72	81	86	.799(72) + .055(81) + .146(86) = 74.6
1/2 Ac.	70	80	85	.799(70) + .055(80) + .146(85) = 72.7
1 Ac.	68	79	84	.799(68) + .055(79) + .146(84) = 70.9

$$.007(77.2) + .162(74.6) + .418(72.7) + .413(70.9) = 72.3$$

$$CN_{Residential} = 72.3$$

b. Calculation of other CN's:

Land Use				
Cultivated	71	78	81	.799(71) + .055(78) + .146(81) = 72.8
Open Space	61	74	80	.799(61) + .055(74) + .146(80) = 64.5
Forest	55	70	77	.799(55) + .055(70) + .146(77) = 59.0
Multi-Family	85	90	92	.799(85) + .055(90) + .146(92) = 86.3
IND-COM	88	91	93	.799(88) + .055(91) + .146(93) = 88.9
Parking Lot	98	98	98	
Dirt	81	88	91	.799(81) + .055(88) + .146(91) = 82.85

c. Calculation of the Final Weighted CN:

$$.153(72.8) + .244(64.5) + .252(59.0) + .257(72.3) + .018(86.3)$$

$$+ .005(98.0) + .027(88.9) + .045(82.85) = 68.4, \text{ use } 68$$

6. As in Step 9 of the preceding Landsat approach, the time flown down the Channel System was 4.26 hours.

7. The time of overland flow requires the land slope. Figure 13 shows the slopes of the soil groups in the watershed in the same format as Figure 12. By counting the number of symbols assigned to each slope, the average watershed slope was estimated to be 8.4% as shown by Table X. From Figure 9, the time of overland flow was computed as 0.13 hours.

8. Time of concentration $T_c = 4.26 + .15 = 4.41$ hours

9. Because T_c is less than 6 hours, use storm duration of 6 hours. From Figure 10a (ES-1020 of Ref. 2) P = 8.2 inches

10. Areal rainfall from Figure 10b: factor: = .94 Therefore P = 7.7"

11. Duration adjustment; not necessary since ppt. is less than 6 hr

12. Runoff Q, Figure 1, CN = 68.01, Q = 4.0"

13. Hydrograph family: Figure 10c Use NO. 3

14. Duration of excess rainfall. T_o: since less than 6 hr Figure 10d Use $T_o = 4.6$

15. $T_p = .7(4.6) = 3.1$ hrs

16. $T_o/T_p = 4.6/3.1 = 1.48$

17. Revised T_o/T_p: Figure 10e Rev. $T_o/T_p = 1.5$

18. Revised T_p; Eq. 21-5 Rev. $T_p = 3.1$

19. Qp: Eq. 21-6 = 484 A/Rev. T_p = 484 (21.1)/3.1 = 3294

20. Q_{qp} = 4(3294) = 13176

21. Hydrograph is listed in Table XI and shown as Figure 11.

VI. COMPARISONS WITH SCS-TR-20

A more extensive SCS Model, the TR-20[3], was used by the Maryland National Capital Park and Planning Commission (MNCPPC) and their consultants in the development of a comprehensive storm water management program for the Anacostia River Basin. The function of the model was to synthesize a flood frequency series for present and future land uses that could be used for flood plain delineation and estimating reservoir storage requirements.

Conceptually, the TR-20 is a more comprehensive, computerized version of the model used in the Landsat and U-2 studies described in the previous section. A key feature of the TR-20 is that it automatically computes hydrographs for individual subwatersheds draining into the channel system and routs them to the downstream end of the drainage basin. Backwater curves are then computed to establish the flood plain.

Land cover for the TR-20 model was delineated by MNCPPC from 1:4800 aerial photos and field investigations. No records were kept concerning the number of man-hours required because the staff was involved in other projects. Discussions with the MNCPPC staff and experiences with 1:4800 aerial photos

during the Anacostia Resource Identification Study[10] indicate that the time required for land use delineation in the upper 21.1 square miles of the basin was at least one and one-half to two man-months. Land covers, soil types, and the corresponding Curve Numbers were developed for 109 sub-watersheds ranging in area from 3.1 acres to 2.36 sq. miles.

As mentioned earlier, the TR-20 collects sub-watershed hydrographs and routs them through the channel system. Thus, channel cross sections are required as inputs to the model. One-hundred and twenty cross-sections were used in the TR-20 for the Upper Anacostia Basin. A commercial surveying firm was hired for the field work. A three man crew was able to complete an average of three cross sections per day. Thus, approximately 40 calendar days, or 120 man-days, were required to establish the cross-sections used in the TR-20 study.

SCS has an option for three antecedent moisture conditions, I, II, and III in their models. The Curve Numbers used in the Landsat and U-2 examples of the previous section were for antecedent moisture condition II. The MNCPPC decided to use antecedent moisture condition III in their work with the TR-20. Table 10.1 of Reference 2 increases the Landsat and U-2 CN's of 64 and 68 to 81 and 84 respectively for the III moisture condition. The weighted Curve Number for the Upper Anacostia as used by MNCPPC in the TR-20 was 80.5. Thus, the Curve Number agreement among the three approaches is truly excellent.

MNCPPC also estimated the percent imperviousness of the Upper Anacostia as part of their land use studies. They estimated that 19% of the watershed was

covered by roof tops or some kind of pavement. The Landsat and U-2 estimates were 15.2% and 15.3% respectively.

Stream cross-section Number 120, used by MNCPPC in the TR-20, was at Randolph Road which coincides with a USGS gaging station established in 1927. Table XII shows the Stage-Cross Sectional Area-Discharge relationship for this station. So that a comparison could be made, the Landsat and U-2 approaches described in the previous section were used to synthesize a flood frequency series with antecedent soil moisture III Curve Numbers. The approach was to compute peak flows produced by the 24-hour rainfalls corresponding to specified return periods. These were the same rainfalls used by MNCPPC.

Figure 14 shows the three synthetic frequency curves. Table XIII compares the discharges and depths of flow estimated by the three approaches. The Landsat and U-2 discharges are higher than those of the TR-20. If the land-use and soil input data to the three approaches were identical one would still expect lower discharges from the TR-20 because of the attenuation produced by flood routing sub-routine. The agreement among the approaches with respect to depth of flow is excellent, especially when one considers the uncertainties concerning river stage during periods of flooding.

There is no way to be certain that the SCS Models provide the best estimates of the flood frequency series. The flood frequency series developed from the long term Upper Anacostia stream flow records by USGS Table XIV cannot be used as a comparison because of the drastic shifts in land use occurring during

the 1960's. However, if an SCS approach is adopted for a study, the results on the Upper Anacostia provide strong indications that the relatively simple Landsat or U-2 approaches are just as good as the TR-20. Of major importance, the inputs required for the Landsat and U-2 approaches can be estimated in a fraction of the time required for the development of the TR-20 inputs.

When making a comparison between Landsat and aerial photographic approaches, one automatically assumes that the photos provide the "ground truth." The U-2 photo blown up to a scale of 1:24,600 allows an interpreter to see every house and small field in the watershed. Still, when it becomes necessary to classify the land uses in accordance with Table I, or some similar breakdown, some confusion develops concerning the exact category to which a particular parcel should be assigned. Table XV is a "confusion matrix" for the two interpreters working on the Upper Anacostia River Basin. The confusion matrix shows that when a large sample is involved, 2707 grid cells in this case, the overall classification represented by the "percent of total" is good. On the other hand, the classification of a single cell or small parcel of land may be confused among several categories just as is the case when using Landsat data.

The confusion matrix presents the number of samples that Interpreter 1 assigned to land use L_i that were assigned to land use L_j by Interpreter 2. For instance, Interpreter 1 assigned 381 samples to the class "cultivated" and of those same 381 samples, Interpreter 2 assigned 223 to the class cultivated, 105 to open space, etc. When large samples are used the values in the matrix can

be divided by the totals of the rows or columns to obtain probability estimates for each assignment. By dividing the first column of Table XV by the column total, 381, one obtains the probability that Interpreter 2 will assign a sample labeled cultivated by Interpreter 1 to each of the land uses. If one of the interpreters is assumed to be 100% accurate the values would represent the probabilities of correct and incorrect assignment. However, in the present study they must be interpreted simply as the probability of agreement and disagreement.

The diagonal elements of the confusion matrix represent the agreement of the two interpreters. The overall agreement is 68%. If the classes Cultivated and Open Space and the classes Parking Lot and Industrial-Commercial are combined into the classes Grass and Highly Impervious respectively the classification scheme is similar to that used for the Landsat data. The probability of agreement is now 77% because confusion between certain classes was removed by combining them.

VII. CONCLUSIONS

The SCS Model is an empirically based approach to hydrograph synthesis. It was selected for examination because the parameters needed for its operation are heavily dependent on land cover distributions that can be modified for Landsat compatibility. If a planning agency decides to use the SCS model, the land cover categories can be developed through computer aided analysis of the Landsat CCT's. The results obtained with the Landsat based approach should compare favorably with those based on the conventional land cover delineations.

The testing program of this study used topographic and conventional soil survey data. In some geographical regions it is possible to extract considerable topographic data such as stream networks, etc., from Landsat[11]. Considerable work is also being done to develop techniques for estimating soil types from Landsat[12] through inferences from stream networks, vegetal cover, tone, and cultural practices. Improvement in the ability to extract topographic and soil information with Landsat should make the satellite based SCS approach an increasingly attractive tool for hydrograph synthesis on ungaged watersheds.

REFERENCES

1. Anonymous, "Urban Hydrology for Small Watersheds," Technical Release No. 55, Soil Conservation Service-USDA, January 1975.
2. Anonymous, National Engineering Handbook Section 4: Hydrology, Soil Conservation Service, Washington, D. C., 1972.
3. Anonymous, "Computer Program for Project Formulation - Hydrology," USDA-SCS Technical Release No. 20, Soil Conservation Service Central Technical Unit, March 1969.
4. Viessman, W., Harbaugh, T. E., and Knapp, J. W., Introduction to Hydrology, Intext Educational Publishers, New York/London, 1972.
5. Chow, V. T., Handbook of Applied Hydrology, McGraw-Hill, New York, 1964.
6. Ragan, R. M., and Jackson, T. J., "Use of Satellite Data in Urban Hydrologic Models," J. of Hydraulics Division, ASCE, December 1975.

7. Roesner, L. A., Nichandros, H. M., Shubinski, R. P., Feldmen, A.D., Abbott, J. W., and Friedland, A. O., "A Model for Evaluating Runoff Quality in Metropolitan Master Planning," ASCE Tech. Memorandum 23, April 1974.

8. Anonymous, "The Urban Studies Program of the Army Corps of Engineers," Report Prepared by the Department of the Army in Support of the FY 1973 Budget, February 1972.

9. Barnes, H. H., "Roughness Characteristics of Natural Channels," USGS Water Supply Paper 1849, U. S. Geological Survey, Washington, D. C., 1967.

10. Ragan, R. M., McCuen, R. H., Rebuck, H. C., and Otts, L. E., "Resource Identification Study of the Anacostia River Basin," Six Volume Final Report to Maryland Department of Natural Resources, Annapolis, Maryland, October 1973.

11. Rango, A., Foster, J., and Salomonson, V. V., "Extraction and Utilization of Space Acquired Physiographic Data for Water Resources Development," Water Resources Bulletin, Amer. Water Res. Assoc., December 1975.

12. Landgrebe, D. A., et al., "A Study of the Utilization of ERTS-1 Data From the Wabash River Basin," LARS Information Note 052375, (Final Rpt. for NASA Contract NAS5-21773), August 1974.

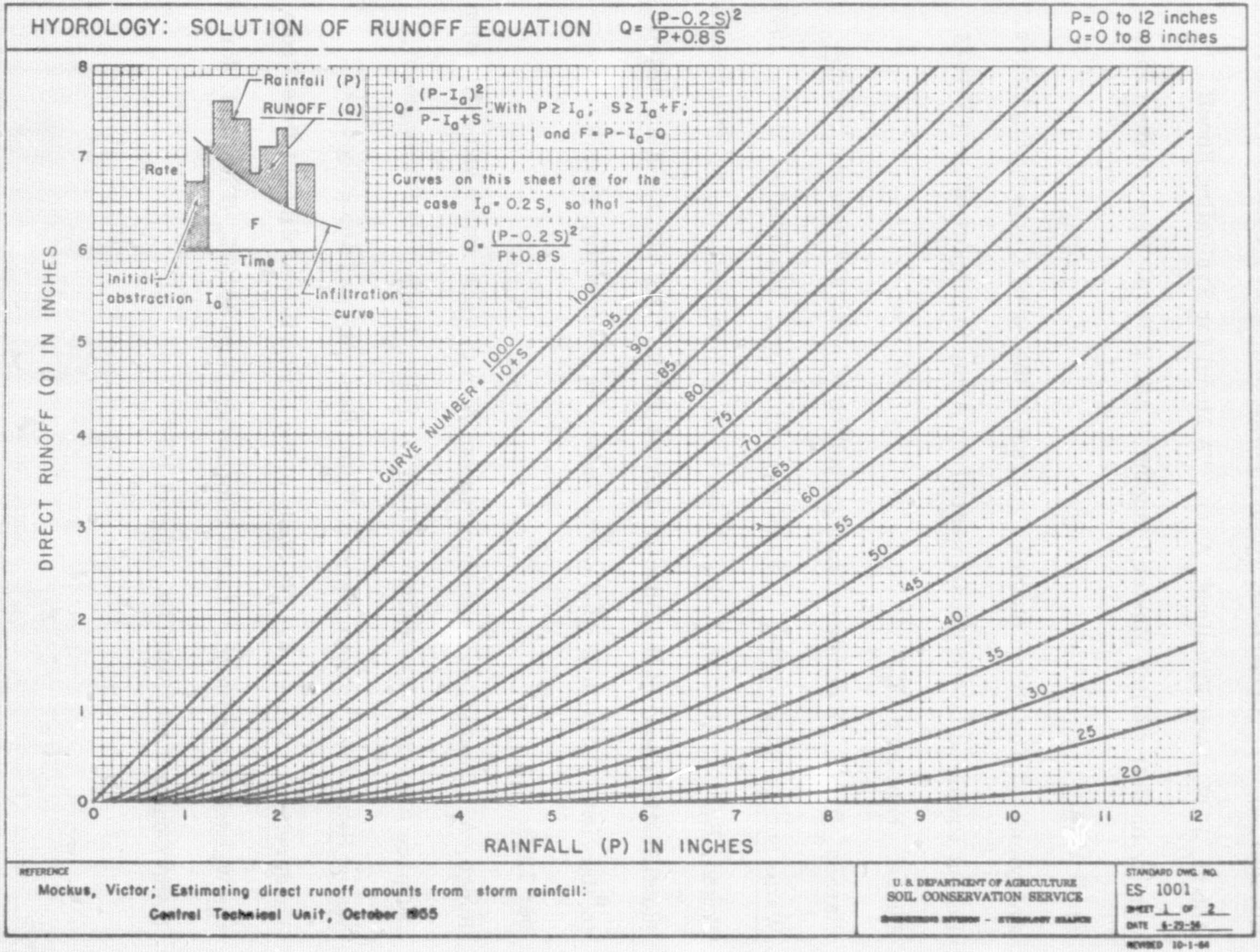

Figure 1. Graphical Solution of Runoff Equation. (Fig. 10.1 of NEH-4)

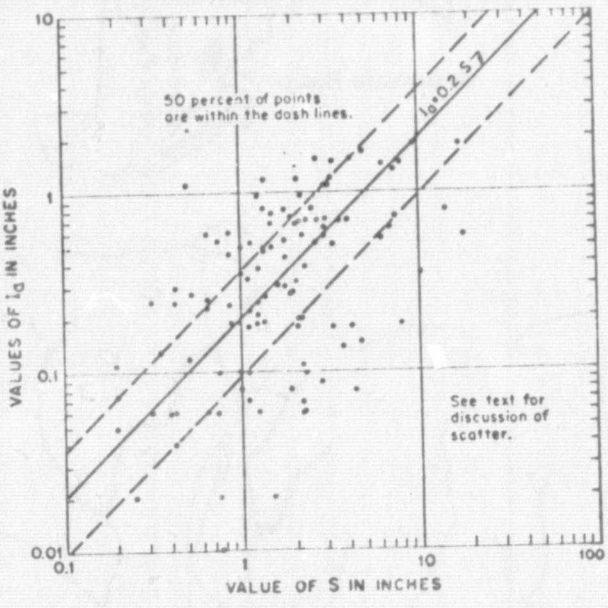

Figure 2. Relationship of I_a and S. Plotted Points are Derived from Experimental Watershed Data (Fig. 10.2 of NEH-4)

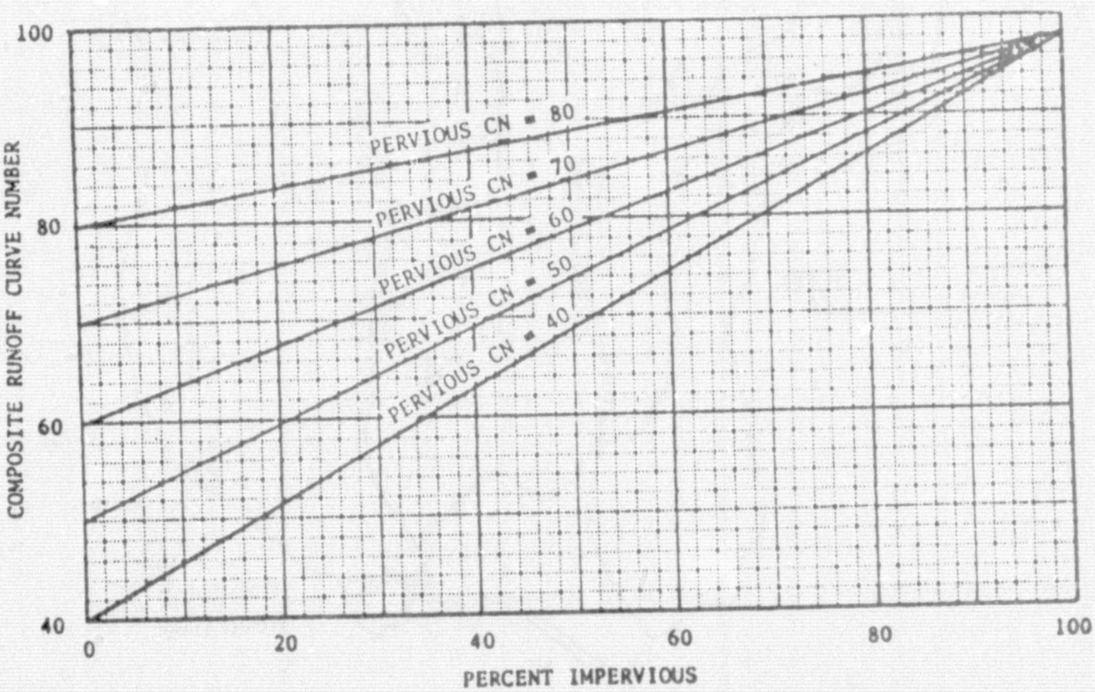

Figure 3. Percentage of Impervious Areas vs. Composite CN's for Given Pervious Area CN's. (Fig. 2.2 of SCS-TR-55)

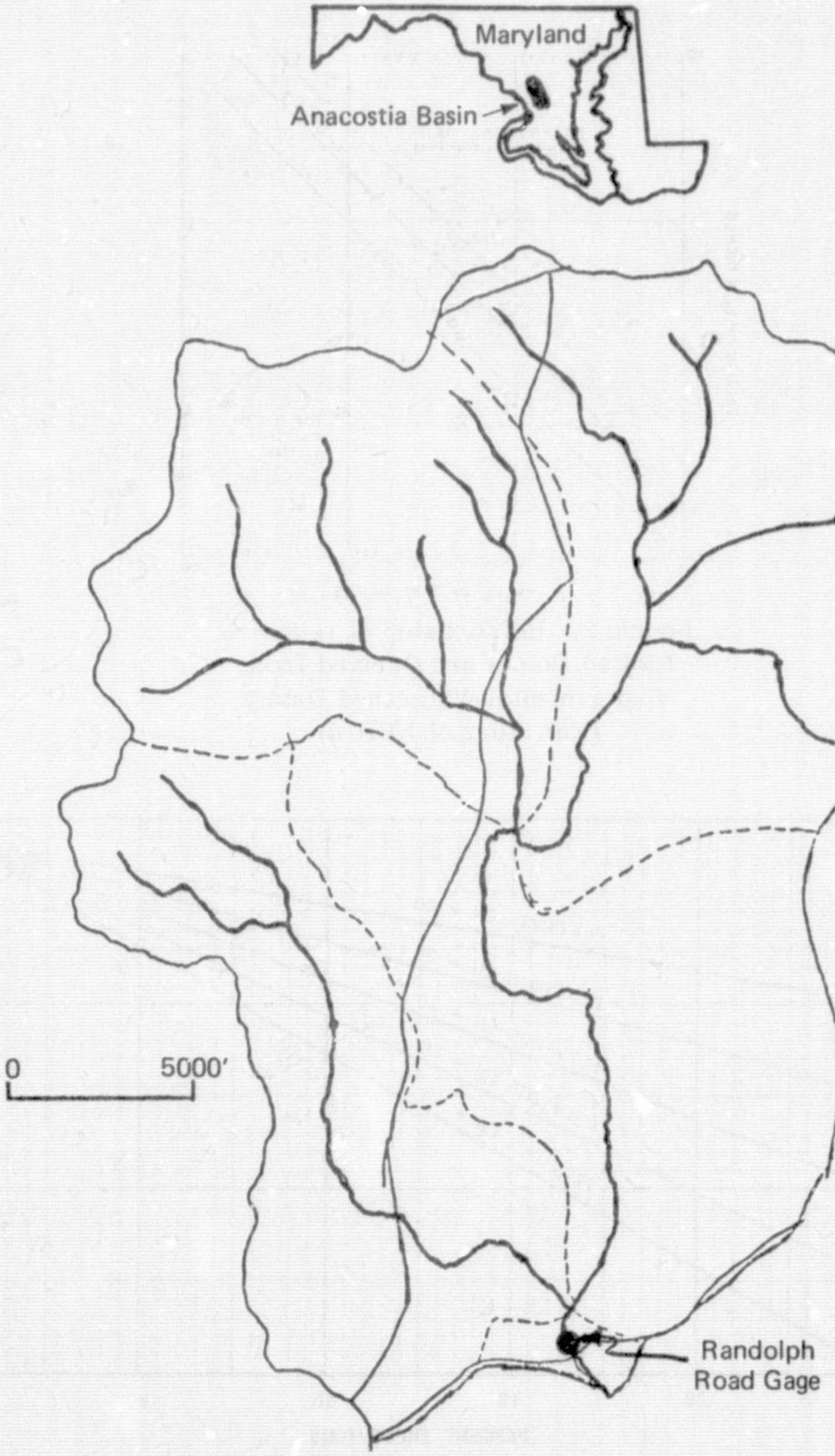

Figure 4. Upper Anacostia River Basin Test Site.

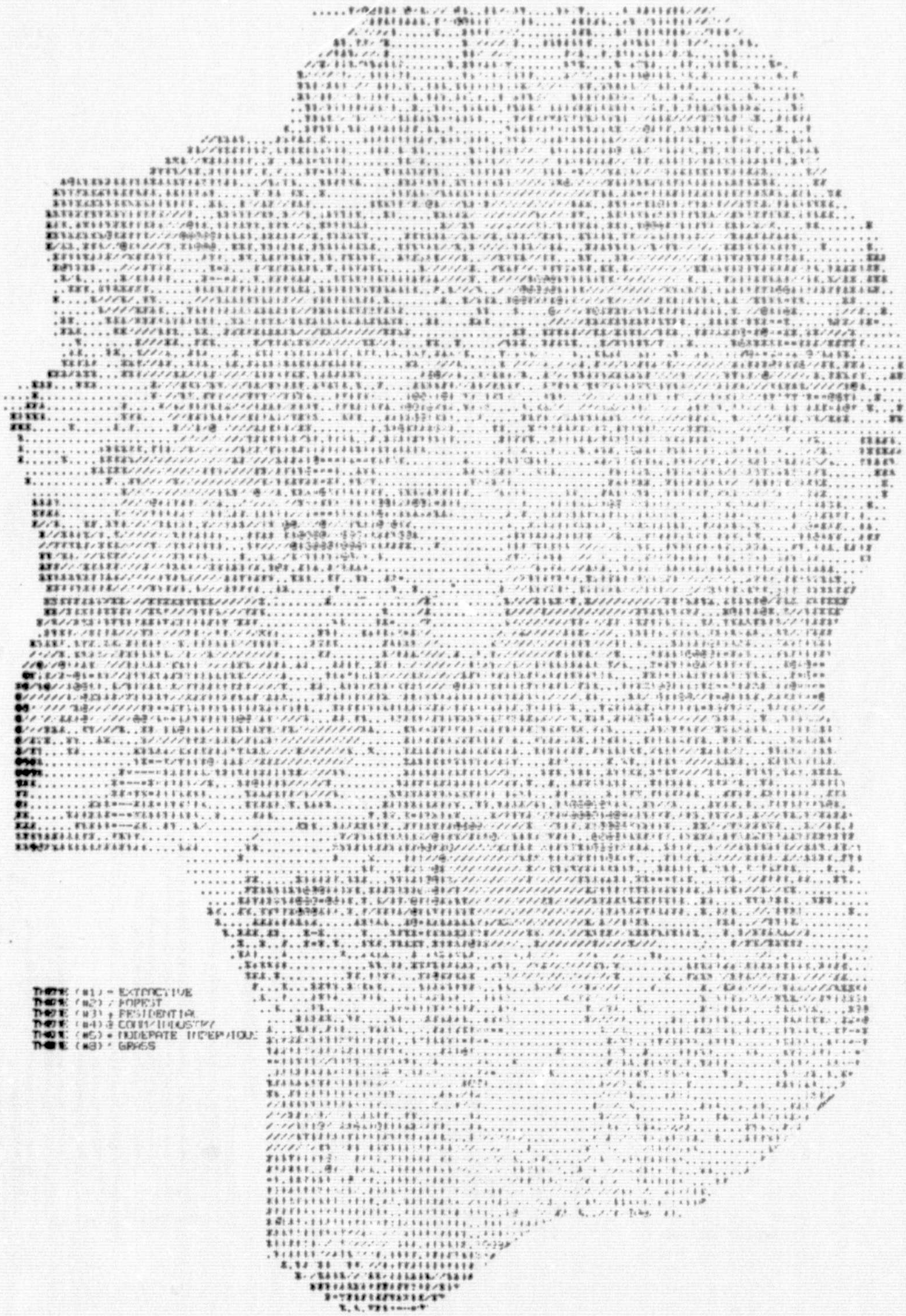

Figure 5. Alpha-Numeric Map of Upper Anacostia River Basin from IMAGE 100 Line Printer.

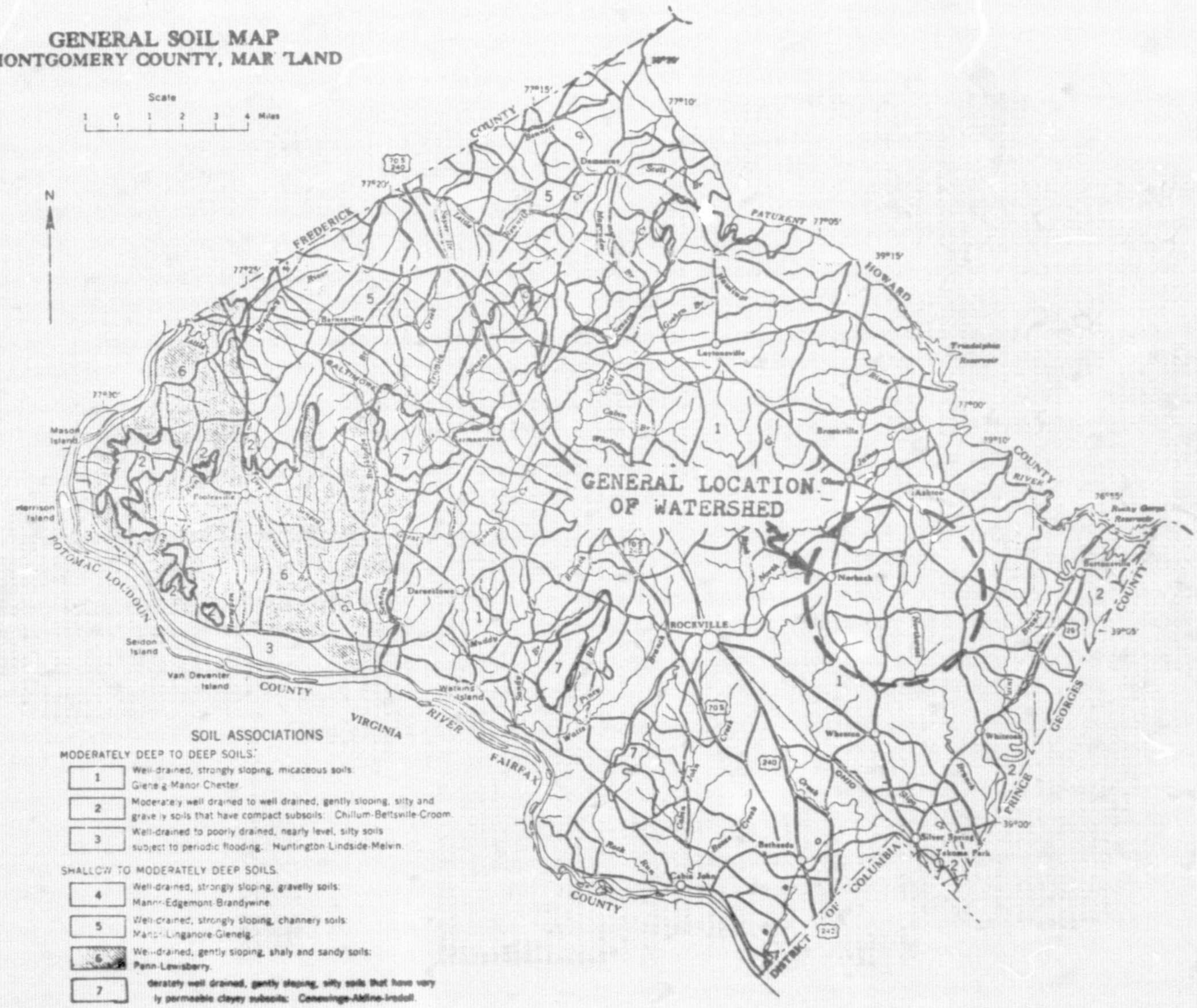

Figure 6. Production of General Soil Map from Montgomery County Soil Survey.

DILLWYN	A	DOUGHTY	A	DU PAGE	B	EGBERT	B/C	EMILY	B
DILMAN	C	DOUGLAS	B	DUPEE	C	EGELAND	B	EMLIN	B
DILTS	D	DOURO	B	DUPLIN	C	EGGLESTON	B	EMMA	C
DILWORTH	D	DOVER	B	DUPO	C	EGNAR	C	EMMERT	A
DIMAL	D	DOVRAY	D	DUPONT	D	EICKS	C	EMMET	B
DIMYAN	C	DOW	B	DUPREE	D	EIFORT	C	EMMONS	C
DINGLE	B	DOWAGIAC	B	DURALDE	C	EKAH	C	EMORY	B
DINGLISHNA	D	DOWDEN	C	DURAND	B	EKALAKA	B	EMPEDRADO	C
DINKELMAN	B	DOWELLTON	D	DURANT	D	ELAM	A	EMPEY	B
DINKEY	A	DOWNER	B	DURELLE	B	ELBERT	D	EMPEYVILLE	C
DINNEN	B	DOWNEY	B	DURHAM	B	ELBURN	B	EMPIRE	C
DINSDALE	B	DOWNS	B	DURKEE	C	ELCO	B	EMRICK	B
DINUBA	B/C	DOXIE	C	DUROC	B	ELD	B	ENCE	B
DINZER	B	DOYCE	C	DURRSTEIN	D	ELDER	B	ENCIERRO	D
DIOXICE	B	DOYLE	A	DUSTON	B	ELDER HOLLOW	[illegible]	ENCINA	B
DIPMAN	D	DOYLESTOWN	D	DUTCHESS	B	ELDERON	B	ENDERS	C
DIQUE	B	DOYN	C	DUTSON	D	ELDON	B	ENDERSBY	B
DISABEL	D	DRA	C	DUTTON	D	ELDORADO	C	ENDICOTT	C
DISAUTEL	B	DRACUT	C	DUVAL	B	ELDRIDGE	C	ENET	B
DISCO	B	DRAGE	B	DUZEL	B	ELEPHANT	D	ENFIELD	B
DISHNER	D	DRAGOON	B	DWIGHT	D	ELEROY	B	ENGLE	B
DISTERHEFF	C	DRAGSTON	C	DWYER	A	ELFRIDA	B	ENGLESIDE	B
DITCHCAMP	C	DRAHAT	D	DYE	D	ELIJAH	C	ENGLEWOOD	C
DITHOD	C	DRAIN	D	DYER		ELIOAK	C	ENGLUND	D
DIVERS	B	DRAKE	B	DYKE	B	ELK	B	ENNIS	B
DIVIDE	B	DRANYON	B	DYRENG	D	ELKADER	B	ENOCHVILLE	B/D
DIX	A	DRAPER	C			ELKCREEK	C	ENOLA	B
DIXIE	C	DRESDEN	B	EACHUSTON	D	ELK HOLLOW	B	ENON	C
DIXMONT	C	DRESSLER	C	EAD	C	ELKHORN	B	ENOREE	D
DIXMORE	B	DREWS	B	EAGAR	B	ELKINS	D	ENOS	B
DIXONVILLE	C	DREXEL	B	EAGLECONE	B	ELKINSVILLE	B	ENOSBURG	D
DIXVILLE	A	DRIFTON	C	EAKIN	B	ELKMOUND	C	ENSENADA	B
DOAK	B	DRIGGS	B	EAMES	B	ELK MOUNTAIN	B	ENSIGN	D
DOBBS	C	DRUM	C	EARLE	D	ELKOL	D	ENSLEY	D
DOBEL	D	DRUMMER	B	EARLMONT	B/C	ELKTON	D	ENSTROM	B
DOBROW	D	DRUMMOND	D	EARP	B	ELLABELLE	B/D	ENTENTE	B
DOBY	D	DRURY	B	EASLEY	D	ELLEDGE	[illegible]	ENTERPRISE	B
DOCAS	B	DRYAD	C	EAST FORK	C	ELLERY	[illegible]	ENTIAT	D
DOCKERY	C	DRYBURG	B	EAST LAKE	A	ELLETT	D	ENUMCLAW	C
DOCT	B	DRY CREEK	C	EASTLAND	C	ELLIBER	A	EPHRAIM	C
DODGE	B	DRYDEN	B	EASTON	C	ELLICOTT	A	EPHRATA	B
DODGEVILLE	B	DRY LAKE	C	EASTONVILLE	A	ELLINGTON	B	EPLEY	B
DODSON	C	DUANE	B	EAST PARK	D	ELLINOR	C	EPOUFETTE	D
DOGER	A	DUART	C	EASTPORT	A	ELLIOTT	C	EPPING	D
DOGUE	C	DUBAKELLA	C	EATONTOWN		ELLIS	D	EPSIE	D
DOLAND	B	DUBAY	D	EAUGALLIE	B/D	ELLISFORDE	C	ERA	B
DOLE	C	DUBBS	B	EBA	C	ELLISON	B	ERAM	C
DOLLAR	B	DUBOIS	C	EBBERT	D	ELLOAM	D	ERBER	C
DOLLARD	C	DUBUQUE	B	EBBS	B	ELLSBERRY	C	ERIC	B
DOLORES	B	DUCEY	B	EBENEZER	C	ELLSWORTH	C	ERIE	C
DOLPH	C	DUCHESNE	B	ECCLES	B	ELLUM	C	ERIN	B
DOMEZ	C	DUCKETT	C	ECHARD	C	ELMA	B	ERNEST	C
DOMINGO	C	DUCOR	D	ECHLER	B	ELMDALE	B	ERNO	B
DOMINGUEZ	C	DUDA	A	ECKERT	D	ELMENDORF	D	ERRAMOUSPE	C
DOMINIC	A	DUDLEY	D	ECKLEY	B	ELMIRA	A	ESCABOSA	C
DOMINO	C	DUEL	B	ECKMAN	B	ELMO	C	ESCAL	B
DOMINSON	A	DUELM	C	ECKRANT	D	ELMONT	B	ESCALANTE	B
DONA ANA	B	DUFFAU	B	ECTOR	D	ELMORE	B	ESCAMBIA	C
DONAHUE	C	DUFFER	D	EDALGO	C	ELMWOOD	C	ESCONDIDO	C
DONALD	B	DUFFIELD	B	EDDS	B	ELNORA	B	ESMOND	B
DONAVAN	B	DUFFSON	B	EDDY	C	ELOIKA	B	ESPARTO	B
DONEGAL		DUFFY	B	EDEN	C	ELPAN	D	ESPIL	D
DONERAIL	C	DUFUR	B	EDENTON	C	EL PECO	C	ESPINAL	A
DONEY	C	DUGGINS	D	EDENVALE	D	EL RANCHO	B	ESPLIN	D
DONICA	A	DUGOUT	D	EDGAR	B	ELRED	B/D	ESPY	C
DONLONTON	C	DUGWAY	D	EDGECUMBE	B	ELROSE	B	ESQUATZEL	B
DONNA	D	DUKES	A	EDGELEY	C	ELS	A	ESS	B
DONNAN	C	DULAC	C	EDGEMONT	B	ELSAH	B	ESSEN	C
DONNARDO	B	DUMAS	B	EDGEWATER	C	ELSINBORO	B	ESSEX	C
DONNYBROOK	D	DUMECQ	C	EDGEWICK	B	ELSINORE	A	ESSEXVILLE	D
DONOVAN	B	DUMONT	B	EDGEWOOD	A	ELSMERE	A	ESTACADO	B
DOOLEY	A	DUNBAR	D	EDGINGTON	C	ELSO	D	ESTELLINE	B
DOONE	B	DUNBARTON	C	EDINA	D	EL SOLYO	C	ESTER	D
DOOR	B	DUNBRIDGE	B	EDINBURG	C	ELSTON	B	ESTERBROOK	B
DORA	D	DUNCAN	D	EDISON	B	ELTOPIA	B	ESTHERVILLE	B
DORAN	C	DUNCANNON	B	EDISTO	C	ELTREE	B	ESTIVE	C
DORCHESTER	B	DUNCOM	D	EDITH	A	ELTSAC	D	ESTO	B
DOROSHIN	D	DUNDAS	C	EDLOE	B	ELWHA	B	ESTRELLA	B
DOROTHEA	C	DUNDAY	A	EDMONDS	D	ELWOOD	C	ETHAN	B
DOROVAN	D	DUNDEE	C	EDMORE	D	ELY	B	ETHETE	B
DORS	B	DUNELLEN	B	EDMUND	C	ELYSIAN	B	ETHRIDGE	C
DORSET	B	DUNE SAND	A	EDNA	D	ELZINGA	B	ETIL	A
DOS CABEZAS	C	DUNGENESS	B	EDNEYVILLE	B	EMBDEN	B	ETNA	
DOSS	C	DUN GLEN	C	EDOM	C	EMBRY	B	ETOE	B
DOSSMAN	B	DUNKINSVILLE	B	EDROY	D	EMBUDO	B	ETOWAH	B
DOTEN	D	DUNKIRK	B	EDSON	C	EMDENT	C	ETOWN	B
DOTHAN	B	DUNLAP	B	EDWARDS	B/D	EMER	C	ETSEL	D
DOTTA	B	DUNMORE	B	EEL	C	EMERALD	B	ETTA	C
DOTY	B	DUNNING	D	EFFINGTON	D	EMERSON	B	ETTER	B
DOUBLETOP	B	DUNPHY	D	EFWUN	A	EMIDA	D	ETTERSBURG	B
DOUDS	B	DUNUL	A	EGAM	C	EMIGRANT	B	ETTRICK	D
DOUGHERTY	A	DUNVILLE	B	EGAN	B	EMIGRATION	D	EUBANKS	B

NOTES   A BLANK HYDROLOGIC SOIL GROUP INDICATES THE SOIL GROUP HAS NOT BEEN DETERMINED
TWO SOIL GROUPS SUCH AS B/C INDICATES THE DRAINED/UNDRAINED SITUATION

NEH Notice 4-102, August 1972

Figure 7. Hydrologic Soil Classifications (from NEH-4(2)).

Soil	Area	Extent
	Acres	Percent
Aldino silt loam, 0 to 3 percent slopes	125	([1])
Aldino silt loam, 3 to 8 percent slopes, moderately eroded	1,212	0.4
Aldino silt loam, 8 to 15 percent slopes, moderately eroded	31	([1])
Aldino silt loam, 8 to 15 percent slopes, severely eroded	32	([1])
Ashton silt loam, 0 to 3 percent slopes	92	([1])
Ashton silt loam, 3 to 8 percent slopes, moderately eroded	73	([1])
Beltsville silt loam, 0 to 3 percent slopes, moderately eroded	463	.1
Beltsville silt loam, 3 to 8 percent slopes, moderately eroded	1,211	.4
Beltsville silt loam, 8 to 15 percent slopes, moderately eroded	109	([1])
Bermudian silt loam, 0 to 3 percent slopes	28	([1])
Bermudian silt loam, 3 to 8 percent slopes	42	([1])
Bowmansville silt loam, 0 to 3 percent slopes	2,343	.7
Brandywine loam, 3 to 15 percent slopes, moderately eroded	298	.1
Brandywine loam, 3 to 15 percent slopes, severely eroded	187	.1
Brandywine loam, 15 to 25 percent slopes, moderately eroded	143	([1])
Brandywine loam, 15 to 25 percent slopes, severely eroded	173	.1
Bucks silt loam, 0 to 3 percent slopes	63	([1])
Bucks silt loam, 0 to 3 percent slopes, moderately eroded	136	([1])
Bucks silt loam, 3 to 8 percent slopes, moderately eroded	1,662	.5
Bucks silt loam, 3 to 8 percent slopes, severely eroded	111	([1])
Bucks silt loam, 8 to 15 percent slopes, moderately and severely eroded	88	([1])
Calvert silt loam, 0 to 8 percent slopes	460	.1
Captina silt loam, 0 to 3 percent slopes	609	.2
Captina silt loam, 3 to 8 percent slopes, moderately eroded	181	.1
Chester silt loam, 0 to 3 percent slopes	742	.2
Chester silt loam, 0 to 3 percent slopes, moderately eroded	193	.1
Chester silt loam, 3 to 8 percent slopes, moderately eroded	10,063	3.2
Chester silt loam, 3 to 8 percent slopes, severely eroded	836	.3
Chester silt loam, 8 to 15 percent slopes, moderately eroded	446	.1
Chester silt loam, 8 to 15 percent slopes, severely eroded	339	.1
Chewacla silt loam, 0 to 3 percent slopes	3,095	1.0
Chillum gravelly silt loam, 3 to 8 percent slopes, moderately eroded	232	.1
Chillum gravelly silt loam, 3 to 8 percent slopes, severely eroded	101	([1])
Chillum gravelly silt loam, 8 to 15 percent slopes, moderately eroded	256	.1
Chillum gravelly silt loam, 8 to 15 percent slopes, severely eroded	140	([1])
Chillum gravelly silt loam, 15 to 25 percent slopes, moderately eroded	174	.1
Chillum gravelly silt loam, 25 to 45 percent slopes, moderately eroded	85	([1])
Chillum silt loam, 3 to 8 percent slopes, moderately eroded	1,404	.4
Chillum silt loam, 8 to 15 percent slopes, moderately eroded	453	.1
Chillum silt loam, 15 to 25 percent slopes, moderately eroded	111	([1])
Chillum and Penn gravelly silt loams, 3 to 8 percent slopes, moderately eroded	994	.3
Chillum and Penn gravelly silt loams, 3 to 8 percent slopes, severely eroded	248	0.1
Chillum and Penn gravelly silt loams, 8 to 15 percent slopes, moderately eroded	161	.1
Chillum and Penn gravelly silt loams, 8 to 25 percent slopes, severely eroded	299	.1
Chrome silt loam, 8 to 15 percent slopes, moderately eroded	140	([1])
Chrome very stony silt loam, 3 to 25 percent slopes, moderately eroded	144	([1])
Chrome and Conowingo silt loams, 3 to 8 percent slopes, moderately eroded	2,229	.7
Chrome and Conowingo silt loams, 3 to 8 percent slopes, severely eroded	71	([1])
Colluvial land	219	.1
Congaree silt loam, 0 to 3 percent slopes	117	([1])
Conowingo silt loam, 0 to 3 percent slopes, moderately eroded	82	([1])
Conowingo silt loam, 0 to 3 percent slopes, severely eroded	359	.1
Croom gravelly loam, 3 to 8 percent slopes, moderately eroded	697	.2
Croom gravelly loam, 8 to 15 percent slopes, moderately eroded	413	.1
Croom gravelly loam, 8 to 15 percent slopes, severely eroded	129	([1])
Croom gravelly loam, 15 to 25 percent slopes, moderately eroded	126	([1])
Croom gravelly loam, 15 to 25 percent slopes, severely eroded	101	([1])
Croom gravelly loam, 25 to 45 percent slopes, moderately eroded	148	([1])
Croom gravelly loam, 25 to 45 percent slopes, severely eroded	116	([1])
Croton silt loam, 0 to 8 percent slopes	2,009	.6
Edgemont gravelly sandy loam, 3 to 8 percent slopes, moderately eroded	42	([1])
Edgemont gravelly sandy loam, 8 to 15 percent slopes, severely eroded	63	([1])
Elioak silt loam, 0 to 3 percent slopes	24	([1])
Elioak silt loam, 3 to 8 percent slopes, moderately eroded	1,562	.5
Elioak silt loam, 8 to 15 percent slopes, moderately eroded	159	.1
Elioak silty clay loam, 3 to 8 percent slopes, severely eroded	246	.1
Elioak silty clay loam, 8 to 15 percent slopes, severely eroded	93	([1])
Elk silt loam, 0 to 3 percent slopes, moderately eroded	38	([1])
Elk silt loam, 3 to 8 percent slopes, moderately eroded	318	.1
Elk silty clay loam, 8 to 15 percent slopes, severely eroded	34	([1])
Eroded land, Penn materials	290	.1
Glenelg channery silt loam, 3 to 8 percent slopes, moderately eroded	4,905	1.6
Glenelg channery silt loam, 3 to 8 percent slopes, severely eroded	1,412	.4
Glenelg channery silt loam, 8 to 15 percent slopes, moderately eroded	784	.2
Glenelg channery silt loam, 8 to 15 percent slopes, severely eroded	847	.3
Glenelg channery silt loam, 15 to 25 percent slopes, moderately eroded	107	([1])
Glenelg channery silt loam, 15 to 25 percent slopes, severely eroded	165	.1
Glenelg gravelly loam, 3 to 8 percent slopes, moderately eroded	101	([1])
Glenelg gravelly loam, 3 to 8 percent slopes, severely eroded	78	([1])

See footnote at end of table.

Figure 8. Montgomery County Soil Distributions.

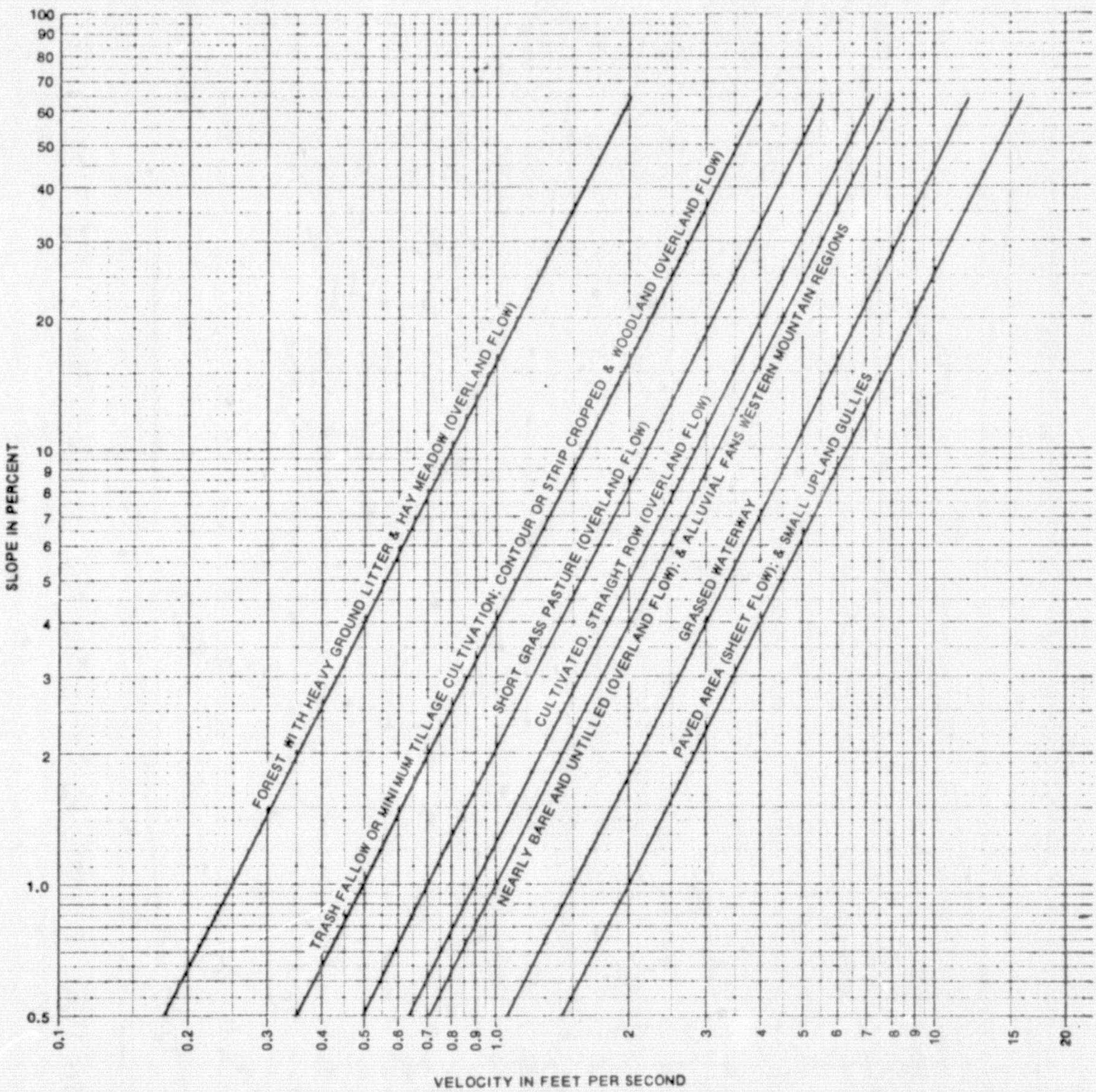

Figure 9. Velocities for Upland Method of Estimating T_c (Fig. 15.2 of NEH-4)

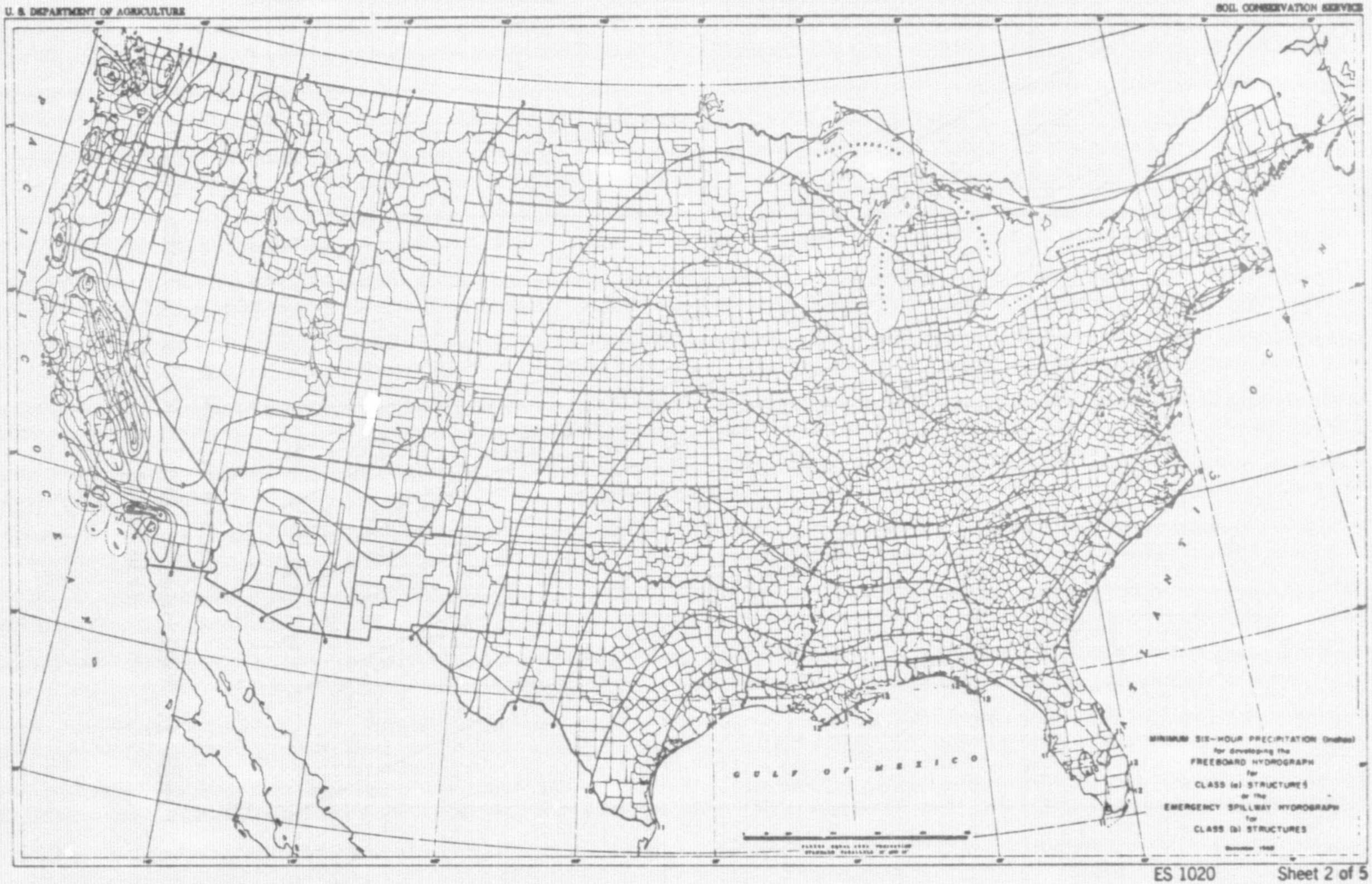

Figure 10(a). Rainfalls for Emergency Spillway Hydrographs. (Fig. 21.5 of NEH-4(2))

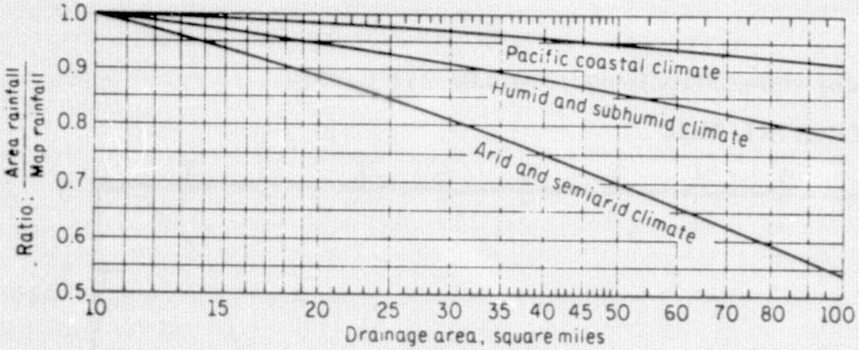

Figure 10(b)

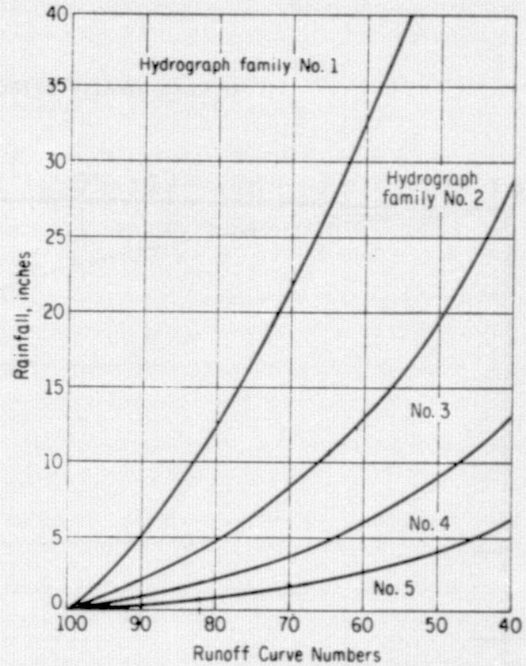

Figure 10(c)

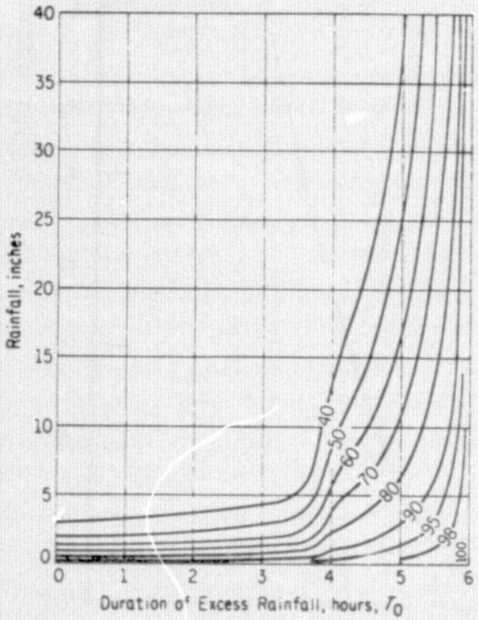

Figure 10(d)

Hydrograph Family	T_o/T_p 1	1.5	2	3	4	6	10	16	25	36	50	75
1	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	*	*	*	*	*	*	*
3	*	*	*	*	*	*	*	*	*	*	*	*
4	*	*	*	*	*	*	*	*	*	*	*	
5	*	*	*	*	*	*	*	*	*	*	*	

Asterisks signify that dimensionless hydrograph tabulations are given in table 21.17.

Figure 10(e)

Figure 10. Misc. Figures used in SCS Computations.

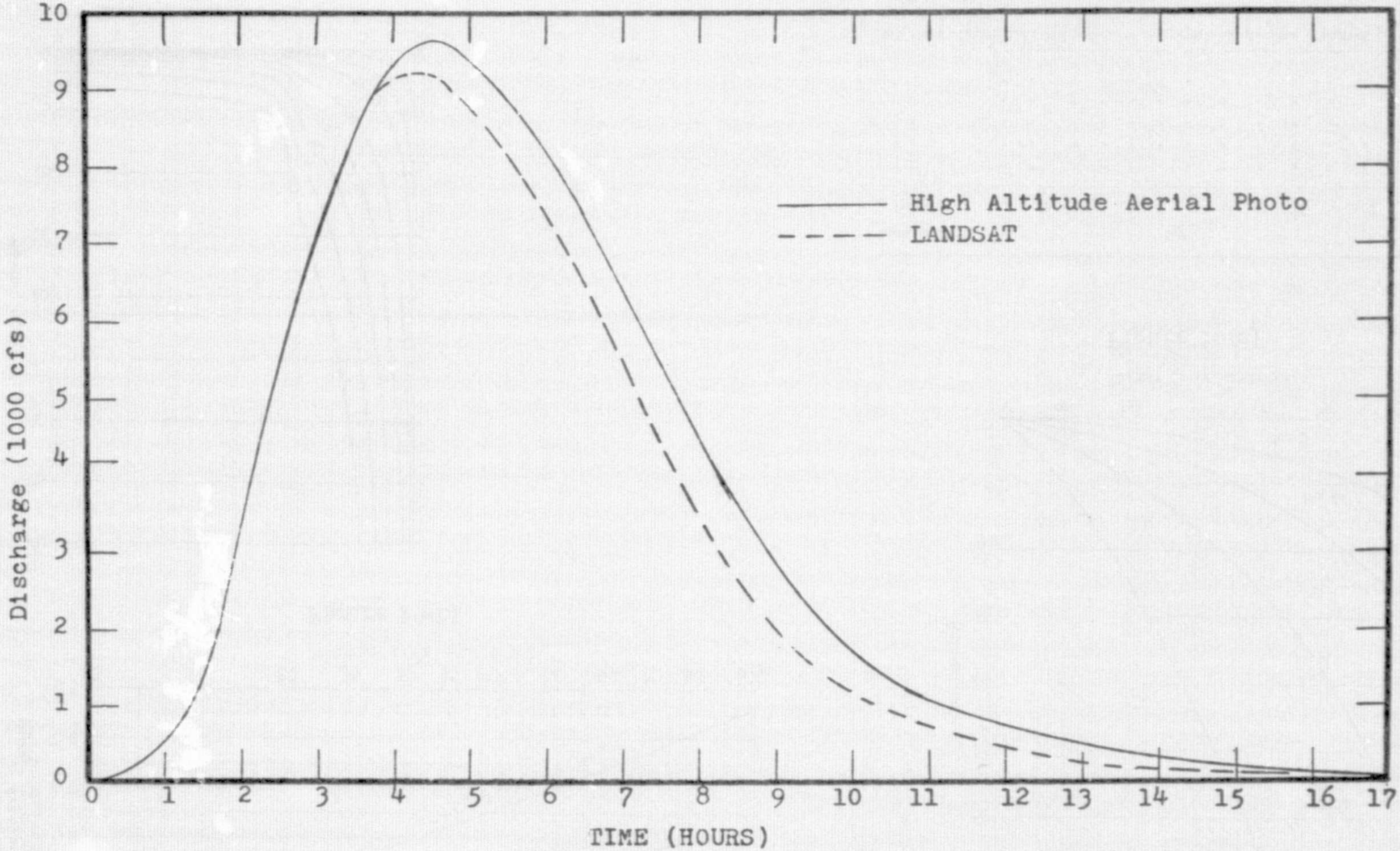

Figure 11. Synthesized Hydrographs for Upper Anacostia River Basin.

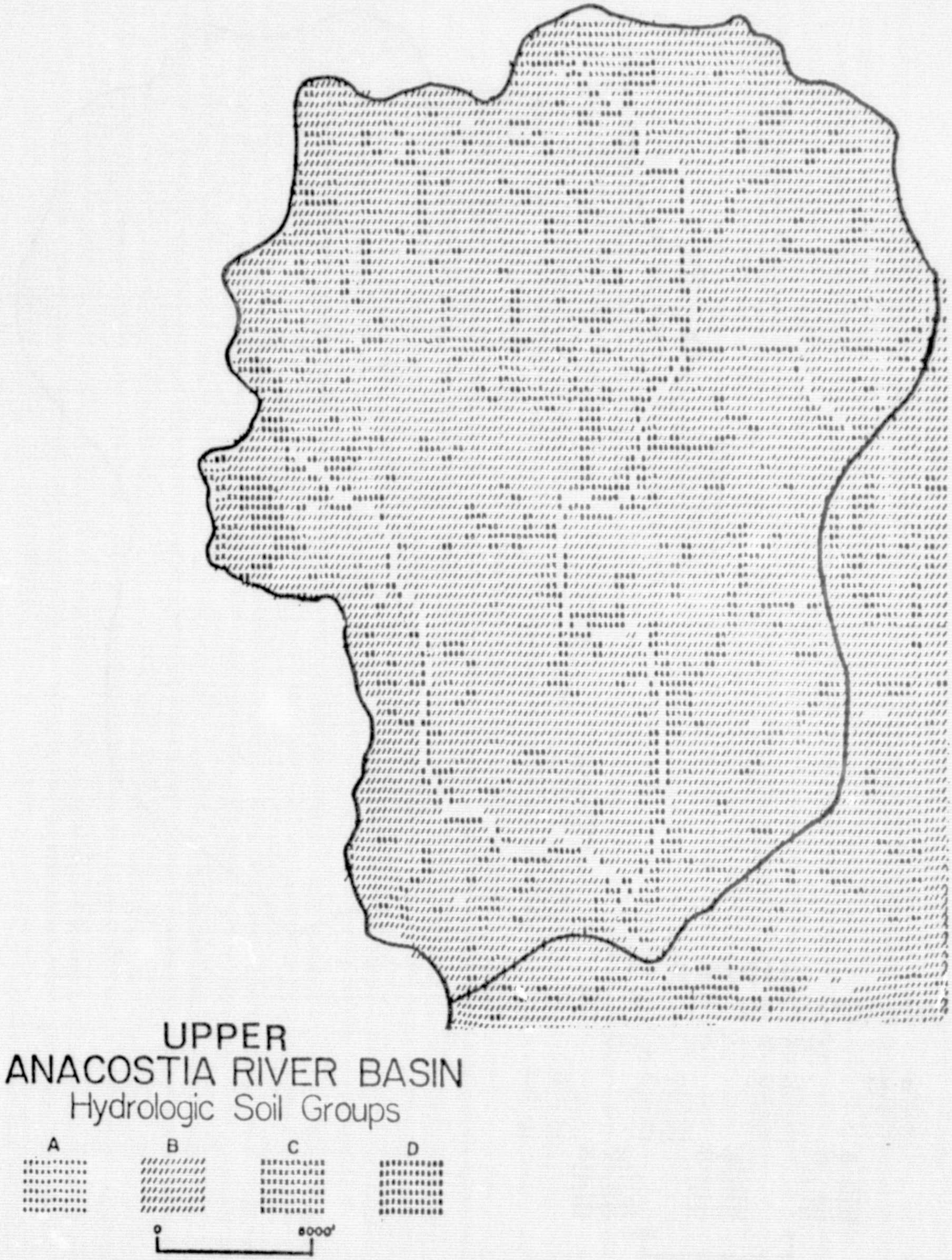
UPPER
ANACOSTIA RIVER BASIN
Hydrologic Soil Groups
A
B
C
D
0
8000'

Figure 12.

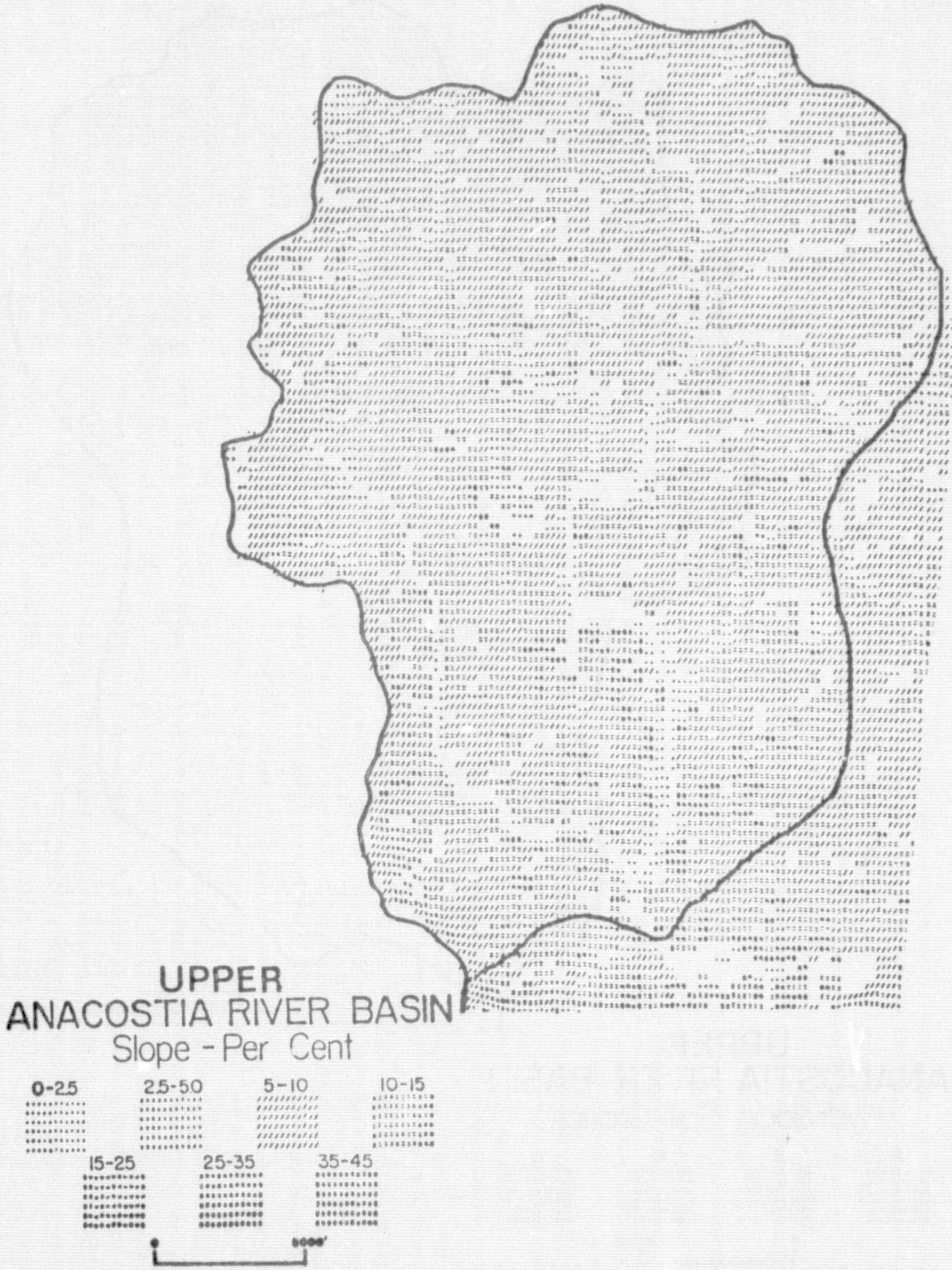
UPPER
ANACOSTIA RIVER BASIN
Slope - Per Cent
0-2.5
2.5-5.0
5-10
10-15
15-25
25-35
35-45
0
5000'

Figure 13.

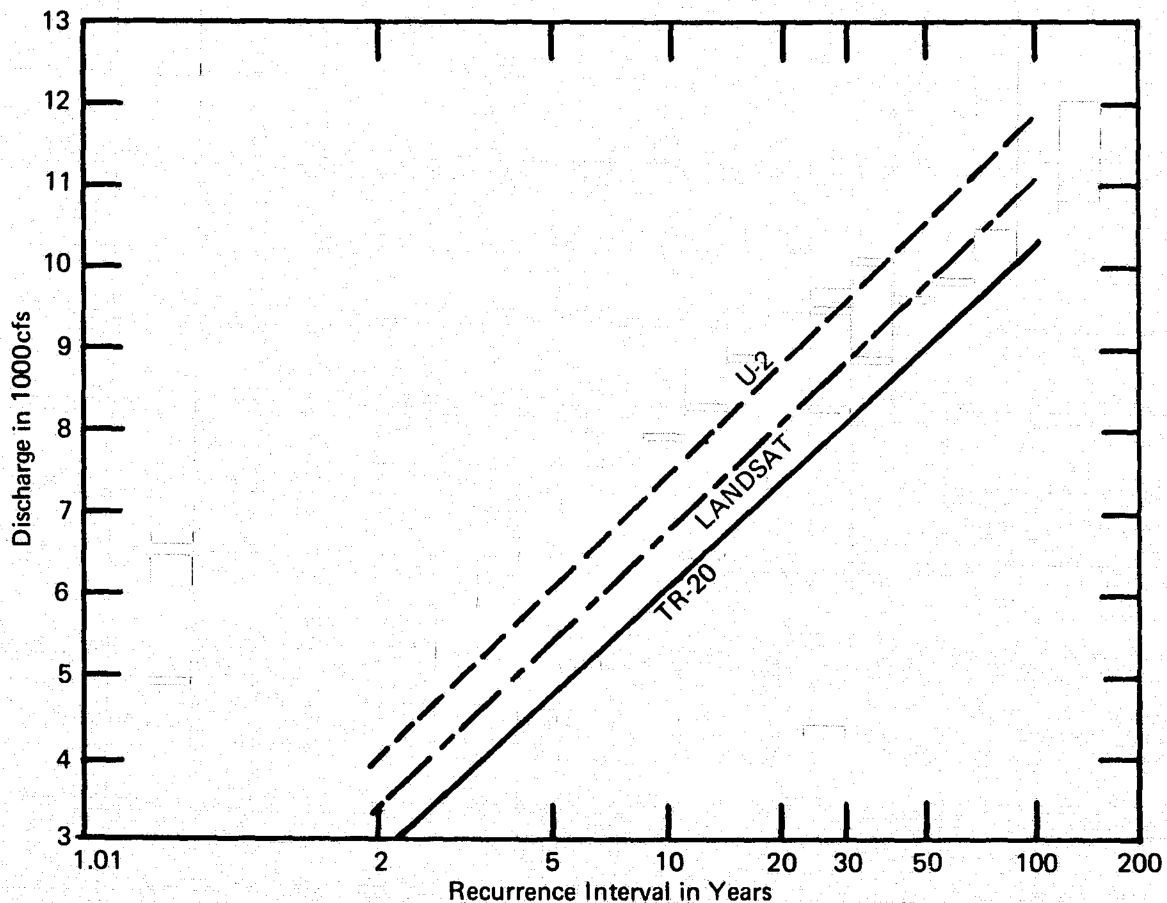

Figure 14. Comparison of Synthetic Frequency Curves. Northwest Branch of Anacostia River at Colesville, Maryland

Table I

Runoff Curve Numbers for Selected Agricultural, Suburban, and Urban Land Use.

(Antecedent moisture condition II, and $I_z = 0.2S$)

(Table 2-2 of SCS-TR-55)

LAND USE DESCRIPTION		HYDROLOGIC SOIL GROUP			
		A	B	C	D
Cultivated land[1/]: without conservation treatment		72	81	88	91
: with conservation treatment		62	71	78	81
Pasture or range land: poor condition		68	79	86	89
good condition		39	61	74	80
Meadow: good condition		30	58	71	78
Wood or Forest land: thin stand, poor cover, no mulch		45	66	77	83
good cover[2/]		25	55	70	77
Open Spaces, lawns, parks, golf courses, cemeteries, etc.					
good condition: grass cover on 75% or more of the area		39	61	74	80
fair condition: grass cover on 50% to 75% of the area		49	69	79	84
Commercial and business areas (85% impervious)		89	92	94	95
Industrial districts (72% impervious).		81	88	91	93
Residential:[3/]					
Average lot size	Average % Impervious[4/]				
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[5/]		98	98	98	98
Streets and roads:					
paved with curbs and storm sewers[5/]		98	98	98	98
gravel		76	85	89	91
dirt		72	82	87	89

[1/] For a more detailed description of agricultural land use curve numbers refer to National Engineering Handbook, Section 4, Hydrology, Chapter 9, Aug. 1972.

[2/] Good cover is protected from grazing and litter and brush cover soil.

[3/] Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[4/] The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

[5/] In some warmer climates of the country a curve number of 95 may be used.

Table II
Soil Names and Hydrologic Classifications.
(Table B-1 of SCS-TR-55)

		AKAKA	A	AMADOR	D	ARBOR	B	ATLEE	C
AASTAD	B	AKASKA	B	AMAGON	D	ARBUCKLE	B	ATMORE	B/D
ABAJO	C	AKELA	C	AMALU	D	ARCATA	B	ATOKA	C
ABBOTT	D	ALADDIN	B	AMANA	B	ARCH	B	ATSION	C
ABBOTTSTOWN	C	ALAE	A	AMARGOSA	D	ARCHABAL	B	ATTERBERRY	B
ABEGG	B	ALAELOA	B	AMARILLO	B	ARCHER	C	ATTEWAN	A
ABELA	B	ALAGA	A	AMASA	B	ARCHIN	C	ATTICA	B
ABELL	B	ALAKAI	D	AMBERSON		ARCO	B	ATTLEBORO	
ABERDEEN	D	ALAMA	C	AMBOY	C	ARCOLA	C	ATWATER	B
ABES	D	ALAMANCE	B	AMCRAW	C	ARD	C	ATWELL	C
ABILENE	C	ALAMO	C	AMEDEE	A	ARDEN	B	ATWOOD	B
ABINGTON	B	ALAMOSA	C	AMELIA	B	ARDENVOIR	B	AUBBEENAUBBEE	B
ABIQUA	C	ALAPAHA	D	AMENIA	B	ARDILLA	C	AUBERRY	B
ABO	B	ALAPAI	A	AMERICUS	A	AREDALE	B	AUBURN	C
ABRA	C	ALBAN	B	AMES	C	ARENA	C	AUBURNDALE	D
ABRAHAM	B	ALBANO	D	AMHERST	C	ARENALES	A	AUDIAN	B
ABSAROKEE	C	ALBANY	C	AMITY	C	ARENDTSVILLE	B	AU GRES	C
ABSCOTA	B	ALBATON	D	AMMON	B	ARENOSA	A	AUGSBURG	B
ABSHER	D	ALBEE	C	AMOLE	C	ARENZVILLE	B	AUGUSTA	C
ACACIO	C	ALBEMARLE	B	AMOR	B	ARGONAUT	D	AULD	D
ACADEMY	C	ALBERTVILLE	C	AMOS	C	ARGUELLO	B	AURA	B
ACADIA	D	ALBIA	C	AMSTERDAM	B	ARGYLE	B	AURORA	C
ACANA	D	ALBION	B	AMTOFT	D	ARIZO	A	AUSTIN	C
ACEITUNAS	B	ALBRIGHTS	C	AMY	D	ARKABUTLA	C	AUXVASSE	D
ACEL	D	ALCALDE	C	ANACAPA	B	ARKPORT	B	AUZQUI	B
ACKER	B	ALCESTER	B	ANAHUAC	D	ARLAND	B	AVA	C
ACKMEN	B	ALCOA	B	ANAMITE	D	ARLING	C	AVALANCHE	B
ACME	C	ALCONA	B	ANAPRA	B	ARLINGTON	A	AVALON	B
ACO	B	ALCOVA	B	ANATONE	D	ARLOVAL	C	AVERY	B
ACOLITA	B	ALDA	C	ANAVERDE	B	ARMAGH	D	AVON	C
ACOVE	C	ALDAX	D	ANCHO	C	ARMINGTON	D	AVONBURG	D
ACTON	B	ALDEN	D	ANCHORAGE	A	ARMO	B	AVONDALE	B
ACUFF	B	ALDER	B	ANCHOR BAY	D	ARMOUR	B	AWBREY	D
ACWORTH	B	ALDERDALE	C	ANCHOR POINT	B	ARMSTER	C	AXTELL	D
ADA	B	ALDERWOOD	C	ANCLOTE	C	ARMSTRONG	D	AYAR	C
ADAIR	D	ALDINO	C	ANCO	C	ARMUCHEE	D	AYCOCK	B
ADAMS	A	ALEKNAGIK	B	ANDERS	C	ARNEGARD	B	AYR	B
ADAMSON	B	ALEX	B	ANDERSON	B	ARNHART	C	AYRES	D
ADAMSTOWN		ALEXANDRIA	C	ANDES	C	ARNHEIM	C	AYRSHIRE	C
ADAMSVILLE	C	ALEXIS	B	ANDORINIA	C	ARNO	D	AYSEES	B
ADATON	D	ALFORD	B	ANDOVER	D	ARNOLD	B	AZTALAN	B
ADAVEN	D	ALGANSEE	B	ANDRES	B	ARNOT	C/D	AZTEC	B
ADDISON	D	ALGIERS	C/D	ANDREWS	C	AROOSTOOK		AZULE	C
ADDY	C	ALGOMA	B/D	ANED	D	AROSA	D	AZWELL	B
ADE	A	ALICE	A	ANETH	A	ARP	D		
ADEL	A	ALICEL	B	ANGELICA	D	ARRINGTON	B	BABB	A
ADELAIDE	D	ALICIA	C	ANGELINA	B/D	ARROLIME	C	BABBINGTON	B
ADELANTO	B	ALIDA	B	ANGIE	C	ARRON	C	BABCOCK	B
ADELPHIA	C	ALIKCHI	B	ANGLE	A	ARROW	B	BABYLON	A
ADENA	C	ALKO	D	ANGLEN	B	ARROWSMITH	B	BACA	C
ADILIS	A	ALLAGASH	B	ANGOLA	C	ARTA	C	BACH	D
ADIRONDACK		ALLARD	B	ANGOSTURA	B	ARTOIS	C	BACHUS	B
ADKINS	B	ALLEGHENY	B	ANIAK	D	ARVADA	D	BACKBONE	A
ADLER	C	ALLEMANDS	D	ANITA	D	ARVANA	C	BADENAUG	B
ADOLPH	D	ALLEN	B	ANKENY	A	ARVESON	C	BADGER	C
ADRIAN	A/D	ALLENDALE	C	ANLAUF	C	ARVILLA	B	BADGERTON	B
AENEAS	B	ALLENSVILLE	C	ANNABELLA	A	ARZELL	C	BADO	D
AETNA	B	ALLENTINE	D	ANNANDALE	C	ASA	B	BADUS	C
AFTON	D	ALLENWOOD	B	ANNISTON	B	ASBURY		BAGDAD	B
AGAR	B	ALLEY	C	ANOKA	A	ASCALON	B	BAGGOTT	D
AGASSIZ	D	ALLIANCE	B	ANONES	C	ASCHOFF	B	BAGLEY	B
AGATE	D	ALLIGATOR	C	ANSELMO	A	ASHCROFT	B	BAHEM	B
AGAWAM	B	ALLIS	D	ANSON	B	ASHBY	C	BAILE	D
AGENCY	C	ALLISON	C	ANTELOPE SPRINGS	C	ASHDALE	B	BAINVILLE	C
AGER	D	ALLOUEZ	C	ANTERO	C	ASHE	B	BAIRD HOLLOW	C
AGNER	B	ALLOWAY		ANT FLAT	C	ASHKUM	C	BAJURA	D
AGNEW	B/C	ALMAC	B	ANTHONY	B	ASHLEY	A	BAKEOVEN	D
AGNOS	B	ALMENA	C	ANTIGO	B	ASH SPRINGS	C	BAKER	C
AGUA	B	ALMONT	D	ANTILON	B	ASHTON	B	BAKER PASS	B
AGUADILLA	A	ALMY	B	ANTIOCH	D	ASHUE	B	BALAAM	A
AGUA DULCE	C	ALOHA	C	ANTLER	C	ASHUELOT	C	BALCH	D
AGUA FRIA	C	ALONSO	B	ANTOINE	C	ASHWOOD	C	BALCOM	B
AGUEDA	B	ALOVAR	C	ANTY	B	ASKEW	C	BALD	C
AGUILITA	B	ALPENA	B	ANWAY	B	ASO	D	BALDER	C
AGUIRRE	D	ALPON	B	ANZA	B	ASOTIN	C	BALDOCK	B/C
AGUSTIN	B	ALPOWA	B	APACHE	D	ASPEN	B	BALDWIN	D
AHATONE	D	ALPS		APAKUIE	A	ASPERMONT	B	BALDY	B
AHL	C	ALSEA	B	APISHAPA	C	ASSINNIBOINE	B	BALE	C
AHLSTROM	C	ALSTAD	B	APISON	B	ASSUMPTION	B	BALLARD	B
AHMEEK	B	ALSTOWN	D	APPIAN	D	ASTATULA	A	BALLINGER	C
AHOLT	D	ALTAMONT	C	APPLEGATE	C	ASTOR	A/D	BALM	B/C
AHTANUM	C	ALTAVISTA	C	APPLETON	C	ASTORIA	B	BALMAN	B/C
AHWAHNEE	C	ALTDORF	D	APPLING	B	ATASCADERO	C	BALON	B
AIBONITO	C	ALTMAR	B	APRON	B	ATCO	B	BALTIC	D
AIKEN	B	ALTO	C	APT	C	ATEPIC	C	BALTIMORE	B
AIKMAN	D	ALTOGA	C	APTAKISIC	B	ATHELWOLD	B	BAMBER	B
AILEY	B	ALTON	B	ARABY		ATHENA	B	BAMFORTH	B
AINAKEA	B	ALTUS	B	ARAGO	B	ATHENS	B	BANCAS	B
AIRMONT	C	ALTVAN	B	ARAPIEN	C	ATHERTON	B/C	BANCROFT	B
AIKITSA	B	ALVIN	B	ARAVE	D	ATHOL	C	BANDERA	B
AIRPORT	D	ALVIRA	C	ARAVETON	B	ATKINSON	B	BANGO	C
AITS	B	ALVISO	D	ARBELA	C	ATLAS	D	BANGOR	B

NOTES A BLANK HYDROLOGIC SOIL GROUP INDICATES THE SOIL GROUP HAS NOT BEEN DETERMINED
TWO SOIL GROUPS SUCH AS B/C INDICATES THE DRAINED/UNDRAINED SITUATION

Table III
Runoff Curve Numbers for Land Cover Delineations
Definable from Landsat.

Land Use Description	Hydrologic Soil Group A	B	C	D
Forest Land	25	55	70	77
Grassed Open Space	36	60	73	78
Highly Imperviousness (Commercial, Industrial, Large Parking Lot)*	90	93	94	95
Residential	60	74	83	87
Bare Ground	72	82	88	90

*Probably sufficient to use CN = 93 for all soils

Table IV
Equations Used with SCS Model
(Table 21.11 of NIH-4)

Equation	No.
$T_p = 0.7\ T_c$	21.4
$\text{Rev. } T_p = \dfrac{T_o}{(T_o/T_p)_{rev.}}$	21.5
$q_p = \dfrac{484\ A}{\text{Rev. } T_p}$	21.6
$t = (t/T_p)\ (\text{Rev. } T_p)$	21.7
$q = (q_c/q_p)\ Q_{q_p}$	21.8

where

A = drainage area in square miles

q = hydrograph rate in cfs

q_c = hydrograph rate in cfs when $Q = 1$ inch

q_p = hydrograph peak rate in cfs when $Q = 1$ inch

Q = design storm runoff in inches

Rev. T_p = revised time to peak in hours

t = time in hours at which hydrograph rate is computed

T_c = time of concentration in hours

T_o = duration of excess rainfall in hours

$(T_o/T_p)_{rev.}$ = revised ratio from table 21.16

T_p = time to peak in hours for CTU design hydrographs

Table V
Computation of Average Slope
(Step 10b. of Page 19)

Soil & Slope	Extent	Weight	Soil & Slope	Extent	Weight
Chester			Manor		
1.5	.2	.3	5.5	4.2	23.1
1.5	.1	.2	11.5	5.1	58.7
5.5	3.2	16.6	20.	3.1	62.0
5.5	.3	1.7	35.	.7	24.5
11.5	.1	1.2	5.5	7.0	38.5
11.5	.1	1.2	11.5	11.	126.5
Glenlg			20.	5.3	106.
5.5	2.0	11.0	35.	1.0	35.
11.5	.5	5.8	11.5	.2	2.3
20.	.1	2.	20.	.1	2.0
5.5	.1	.6	35.	.2	7.
11.5	.1	1.2	55.	.2	11.
1.5	.1	.2			
5.5	14.6	80.3	2	63.1	658.8
11.5	2.9	33.4			
20.	.5	10.	Ave. Slope = 10.4%		
35.	.1	3.5			

Table VI
Dimensionless Hydrograph from NEH-4
(Part of Table 21.17 of NEH-4(2))
Hydrograph Family 3

Line No.	$T_o/T_p = 1$ t/T_p	q_c/q_p	Q_t/Q	$T_o/T_p = 1.5$ t/T_p	q_c/q_p	Q_t/Q	$T_o/T_p = 2$ t/T_p	q_c/q_p	Q_t/Q
1	0	0	0	0	0	0	0	0	0
2	.26	.048	.005	.29	.028	.003	.30	.012	.001
3	.52	.219	.030	.58	.190	.025	.60	.123	.016
4	.78	.521	.101	.87	.450	.094	.90	.343	.068
5	1.04	.762	.224	1.16	.656	.212	1.20	.570	.169
6	1.30	.844	.378	1.45	.734	.360	1.50	.657	.304
7	1.56	.778	.533	1.74	.685	.511	1.80	.630	.447
8	1.82	.621	.668	2.03	.585	.646	2.10	.562	.578
9	2.08	.441	.769	2.32	.445	.756	2.40	.484	.694
10	2.34	.305	.841	2.61	.350	.841	2.70	.379	.789
11	2.60	.214	.891	2.90	.199	.899	3.00	.267	.861
12	2.86	.149	.925	3.19	.132	.934	3.30	.177	.910
13	3.12	.103	.949	3.48	.089	.958	3.60	.116	.942
14	3.38	.070	.966	3.77	.057	.973	3.90	.076	.964
15	3.64	.048	.977	4.06	.038	.983	4.20	.050	.977
16	3.90	.034	.985	4.35	.025	.990	4.50	.033	.987
17	4.16	.024	.991	4.64	.015	.994	4.80	.020	.992
18	4.42	.016	.995	4.93	.008	.997	5.10	.011	.996
19	4.68	.010	.997	5.22	.005	.998	5.40	.006	.998
20	4.94	.006	.999	5.51	.003	.999	5.70	.004	.999
21	5.20	.003	1.000	5.80	.002	1.000	6.00	.002	1.000
22	5.46	.001	1.000	6.09	.001	1.000	6.30	.001	1.000
23	5.72	0	1.000	6.38	0	1.000	6.60	0	1.000

Table VII
Hydrograph Tabulation for Landsat Experiment

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

HYDROGRAPH COMPUTATION

DATE ______
COMPUTED BY ______
CHECKED BY ______

WATERSHED OR PROJECT Upper Anacostia LANDSAT Test

STATE Md.

STRUCTURE SITE OR SUBAREA Randolph Rd.

DR. AREA 21.1 SQ. MI. STRUCTURE CLASS b

T_c 4.4 HR. STORM DURATION 6 HR.

POINT RAINFALL 8.2 IN.

ADJUSTED RAINFALL:

AREAL: FACTOR .94 IN. 7.7

DURATION: FACTOR — IN. ______

RUNOFF CURVE NO. 64

Q 3.6 IN.

HYDROGRAPH FAMILY NO. 3

COMPUTED T_p 3.1 HR.

T_o 4.4 HR.

(T_o / T_p):

COMPUTED 1.42 ; USED 1.5

REVISED T_p 2.93

$q_p = \frac{484A}{\text{REV. } T_p}$ = 3485 CFS.

$(Q)(q_p)$ = 12546 CFS.

t(COLUMN) = (t/T_p) REV. T_p q(COLUMN) = $(q_c/q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t/Q)Q$

	$t = (t/T_p)$ Rev. T_p	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t	q	Q
	HOURS	CFS	INCHES
1	0	0	0
2	.85	351	
3	1.70	2385	
4	2.55	5648	
5	3.40	8234	
6	4.25	9212	
7	5.10	8598	
8	5.95	7342	
9	6.80	5585	
10	7.65	4393	
11	8.50	2568	
12	9.35	1657	
13	10.20	1122	
14	11.05	715	
15	11.90	478	
16	12.75	314	
17	13.60	188	
18	14.40	101	
19	15.29	63	
20	16.14	38	
21	16.99	25	
22	17.84	12	
23	18.70	0	
24			
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Table VIII
Land Uses from High Altitude Photography

Land Use	Interpretor 1	Interpretor 2	Average
Cultivated	14.1%	16. [illegible]	15.3%
Open Space	28.1%	20.8%	24.4%
Forest	22.7%	27.6%	25.2%
Residential	24.9%	26.5%	25.7%
Multi-Family	1.8%	1.8%	1.8%
Parking Lot	.4%	.6%	.5%
IND-COMM	3.0%	2.4%	2.7%
Bare Soil	5.0%	3.9%	4.5%

Table IX
Lot Sizes in Residential Areas

Lot Size	Percent of Total Residential Areas
1/4 Acre	0.7%
1/3 Acre	16.2%
1/2 Acre	41.8%
1 Acre	41.3%

Table X
Computation of Average Slope

SLOPE RANGE	AVG. 5	% of the Watershed
0-2.5%	1.25%	9.5
2.5-5%	3.75%	3.8
5-10%	7.5%	60.9
10-15%	12.5%	21.9
15-25%	20%	3.7
35-45%	40%	0

$$.095(1.25) + .038(3.75) + .609(7.5) + .219(12.5) + .037(20) + .002(30) = 8.37 = 8.4\%$$

Table XI
Hydrograph Tabulation for High Altitude Experiment

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

HYDROGRAPH COMPUTATION

DATE ~~~
COMPUTED BY ~~~
CHECKED BY ~~~

WATERSHED OR PROJECT Upper Anacostia
High Altitude Photo Test

STATE Md.

STRUCTURE SITE OR SUBAREA Randolph Rd.

DR. AREA 21.1 SQ. MI. STRUCTURE CLASS 6

T_c 4.4 HR. STORM DURATION 6 HR.

POINT RAINFALL 8.2 IN.

ADJUSTED RAINFALL:

AREAL : FACTOR .94 IN. 7.7

DURATION : FACTOR – IN. –

RUNOFF CURVE NO. 68

Q 4.0 IN.

HYDROGRAPH FAMILY NO. 3

COMPUTED T_p 3.1 HR.

T_o 4.4 HR.

(T_o / T_p):

COMPUTED 1.48 ; USED 1.5

REVISED T_p 3.1

$q_p = \frac{484A}{REV.\ T_p}$ = 3294 CFS.

$(Q)(q_p)$ = 13176 CFS.

t(COLUMN) = (t / T_p) REV. T_p q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$

	$t = (t/T_p)$ Rev. T_p	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t	q	Q
	HOURS	CFS	INCHES
1	0	0	0
2	.9	369	
3	1.8	2503	
4	2.7	5929	
5	3.6	8643	
6	4.5	9671	
7	5.4	9025	
8	[illegible]2	7708	
9	7.[illegible]	5863	
10	8.1	4414	
11	9.0	2622	
12	9.9	1739	
13	10.8	1173	
14	11.68	791	
15	12.59	501	
16	13.49	329	
17	14.38	198	
18	15.28	105	
19	16.18	66	
20	17.08	40	
21	17.98	26	
22	18.88	13	
23	19.78	0	
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Table XII
Flow Characteristics at Randolph Road

	Elevation	Flow Area (ft^2)	Discharge (cfs)
Bottom	242.8	0	0
Bankfall	248.5	323.8	1139.1
1	249.4	496.2	1320.2
2	258.6	829.2	2177.2
3	251.4	1107.04	2941.6
4	252.5	1495.6	4169.2
5	253.3	1826.8	5327.3
6	254.2	2194.6	6716.9
7	257.1	3425.8	12,090.6

Table XIII
Discharges and River Stages Computed with SCS Models
Randolph Road Gaging Station on Northwest Branch of Anacostia River

Return Period (yrs)	Precip. (in)	Discharge (cfs)			Depth of Flow (ft)		
		TR-20	LANDSAT	U-2	TR-20	LANDSAT	U-2
2	3.0	2990	3490	3850	8.9	9.3	9.6
5	3.3	4610	5140	6064	10.0	10.4	10.9
10	5.4	6210	6900	7580	10.9	11.3	11.7
25	5.8	7390	8759	9300	11.7	12.3	12.7
50	6.7	9020	9900	10400	12.5	13.0	13.3
100	7.3	10,780	11,100	11,806	13.5	13.6	14.1

Table XIV
Flood Frequency Series for Upper Anacostia Based on Long Term
Streamflow Records 1923-1970 (USGS)

Return Period	2	5	10	25	50	100
Discharge (cfs)	1200	1980	2680	3800	4860	6130

Table XV
Confusion Matrix for Land Use Interpretation
Form U-2 Photo on the Upper Anacostia

		Interpretor 1									
	Land Use	Cultivated	Open Space	Forested	Residential Single	Residential Multiple	Parking Lots	Industry/Commerce	Bare Soil	Total Cells	Percent of Total
Interpretor 2	Cultivated	223.0	143.0	14.0	20.0	0.0	0.0	4.0	41.0	445.0	16.4
	Open Space	105.0	382.0	21.0	34.0	3.0	2.0	6.0	10.0	563.0	20.8
	Forested	14.0	133.0	541.0	46.0	2.0	0.0	5.0	6.0	747.0	27.6
	Residential Single	16.0	84.0	32.0	548.0	0.0	0.0	30.0	6.0	716.0	26.5
	Residential Multiple	0.0	1.0	0.0	5.0	40.0	0.0	4.0	0.0	50.0	1.8
	Parking Lots	0.0	3.0	2.0	2.0	0.0	6.0	3.0	0.0	16.0	0.6
	Industry/Commerce	1.0	7.0	2.0	17.0	3.0	4.0	29.0	1.0	64.0	2.4
	Bare Soil	22.0	7.0	2.0	3.0	0.0	0.0	0.0	72.0	106.0	3.9
	Total Cells	381.0	760.0	614.0	675.0	48.0	12.0	81.0	136.0	2707.0	
	Percent of Total	14.1	28.1	22.7	24.9	1.8	0.4	3.0	5.0		